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BRITISH
MANUFACTURING INDUSTRIES.

EDITED BY

G. PHILLIPS BEVAN, F.G.S.

IRON AND STEEL,

BY W. MATTIEU WILLIAMS, F.R.A.S., F.C.S., &c.

COPPER SMELTING,

BY J. ARTHUR PHILLIPS, Mem. Inst. C.E., F.G.S., F.C.S., &c.

BRASS FOUNDING, TIN PLATE AND ZINC WORKING,

BY WALTER GRAHAM.

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PREFACE.

THE object of this series is to bring into one focus the leading features and present position of the most important industries of the kingdom, so as to enable the general reader to comprehend the enormous development that has taken place within the last twenty or thirty years. It is evident that the great increase in education throughout the country has tended largely to foster a simultaneous interest in technical knowledge, as evinced by the spread of Art and Science, Schools, Trade Museums, International Exhibitions, &c.; and this fact is borne out by a perusal of the daily papers, in which the prominence given to every improvement in trade or machinery attests the desire of the reading public to know more about these matters. Here, however, the difficulty commences, for the only means of acquiring this information are from handbooks to the various manufactures (which are usually too minute in detail for general instruction), from trade journals and the reports of scientific societies; and to obtain and systematize these scattered details is a labour and a tax upon time and patience which comparatively few persons care to surmount. In these volumes all these facts are gathered together and presented in as readable a form as is compatible with accuracy and a freedom from superficiality; and though they do not lay claim to being a technical guide to each industry, the names of the contributors are a sufficient guarantee that they are a reliable and standard work of reference. Great stress is laid on the progressive developments of the manufactures, and the various applications to them of the collateral arts and sciences; the history of each is truly given, while present processes and recent inventions are succinctly described.

BRITISH MANUFACTURING INDUSTRIES.

IRON.

BY W. William MATTIEU WILLIAMS, F.R.A.S., F.C.S., &c.

THOSE who have studied the prehistoric vestiges of humanity divide the earliest annals of the race into three great periods. First, "the Stone period," in which the absence of any trace of metal among human remains, and the abundance of flint implements with a few stone vessels, show how the rudest savages supplemented the functions of their teeth and finger-nails by means of the hardest and handiest things that could be picked up on the *surface* of the earth.

Many stages of progress are traced in this primitive age of flint; but in passing from the highest of these to the second, viz. "*the Bronze period*," a great stride was made in human progress. A knowledge of the arts of reducing, alloying, casting, forging, and a sort of tempering of metals was then obtained, and with these, as may be supposed, a great advance in all the other arts.

The bronze of the ancients is composed of tin and copper, and has the important property of attaining various degrees of hardness according to the rate of cooling from the fused state. When rapidly cooled, it is soft, when slowly, hard. The importance of this property, when steel was yet unknown, is easily understood; it enabled the artificer to make tools of metal capable of fashioning the same metal,—tools by which others might, while soft, be cut or hammered into shape, and then by hardening become capable of industrial retaliation.

In the absence of direct and sufficient historical evidence, I will venture to supplement our dim knowledge of these distant epochs by some metallurgical inferences, which afford fair grounds for concluding that the wide gap of human progress between the flint and bronze periods was bridged over by gold and silver; that gold was the first metal discovered and used by man; that silver followed gold, and then the materials for bronze; to be succeeded after a long interval by steel and iron.

Gold is found pure in its metallic state, and, like flints, may be picked up on the *surface* of the earth. Although existing in such small quantities in any given place, it is one of the most widely diffused of all the heavy metals. The beautiful colour and lustre of a nugget or grain of gold would attract the attention of the rudest savage; and the facility with which it may be beaten into shape by stone tools, would afford him his earliest ideas of a metal and its properties. Silver is also found in the metallic state, but not so superficially as gold.

Excepting platina and its companions, the metal which, next to silver, is the most liable to occur in the solid and metallic state, is copper. Men who had already learned to value gold, were not likely to pass unheeded an accidental discovery of a vein of native copper, and would probably struggle to utilize its most common ore, the gold-like copper pyrites, which is so easily reduced that an attempt to fuse it in a wood fire would lead to the separation of more or less perfect metal, while the same attempt made upon the similar gold-like iron pyrites would assuredly fail.

But why should tin have preceded iron, seeing that it does not occur in the metallic state, and that its ore is an oxide having no metallic lustre, but of stony or earthy aspect? To this fair question I will venture an hypothetical answer. Until metallic cooking vessels were constructed, water was boiled in vessels of rudely baked clay by throwing heated pebbles into it. The Cornish savages who performed this operation on the banks of the streams must have picked up tin stones with the other pebbles; these when heated in a wood fire would become deoxidized and fused, and thus buttons of a bright silvery malleable metal would be found among the ashes of the spent fire. As copper pyrites exist side by side with the tin-stone of Cornwall, it is not improbable that an accidental alloy of copper and tin may have been made there at a very early date by the reduction and fusing of both in the same fire. These are good mineralogical reasons for the facts connected with England's first appearance on the field of history; and they explain why, during the age of bronze, its south-west shores should have been visited by the Phœnician merchants, and called by them the "land of tin."

or *leadstone*, from its magnetic properties, was probably one of the first used. It is nearly pure, containing rather more than 72 per cent. of iron, and is now called "magnetic oxide."

The object being to separate the oxygen, something must be used which under available circumstances has a greater affinity for oxygen than iron has under the same circumstances. Nothing has yet been discovered that is more efficient for this purpose than carbon, and no form of carbon is better than charcoal, which is made by imperfectly burning some kind of organic substance, such as sugar, starch, flour, wood, &c. The latter is of course the most available under ordinary circumstances, and doubtless was the earliest known.

The characteristic property of carbon upon which its value as a fuel depends, is, that at common temperatures it is chemically inert in reference to oxygen, but when heated, it combines with oxygen so vigorously as to take it away from almost every other substance. When we reflect on this, remembering that combustion is nothing more nor less than combination with oxygen, the beneficence to man of this differential affinity of carbon for oxygen is seen to be immense. If it had the same affinity cold as hot, neither coal nor wood nor any dry vegetable substance could be stored at all, but would blaze out spontaneously on coming in contact with the air. If its affinity when hot were no greater than when cold, all our now familiar fuel would be void of fuel properties, and our usual means of reducing metals from their ores would not exist.

Within certain limits, the affinity of carbon goes on increasing with the elevation of temperature, and simultaneously with this, the hold which the oxygen of a metallic oxide has upon the metal progressively loosens, until at last we reach a temperature at which the oxide would be "dissociated," i. e. separated into pure metal and oxygen, by the repulsive agency of heat alone. This temperature of dissociation varies with the different metals. In the case of iron it is very high, and its exact degree is not yet known. In a furnace urged by a blast it is so nearly approached, that the increased affinity of the carbon for oxygen overpowers the diminished attraction of the iron, and thus instead of free carbon and oxide of iron an exchange is made, and we have free iron and oxide of carbon in the form of gas.

With these principles before him, the reader may now invent for himself the means of iron-making from simple ores. He has only to construct a furnace wherein a mixture of charcoal and ore in contact with each other shall be raised to a high temperature. To obtain the required heat a blast is necessary, and to prevent its wasteful dissipation, an enclosure by a wall of badly-conducting and refractory material is desirable. Clay when baked is such a material, some kinds of clay resisting heat better than others. These are "fire-clays," and with fire-bricks made from these our simple furnace may be constructed.

But how and where shall the blast be applied, top, middle, or bottom, of this fire-brick case. Seeing that the oxide of carbon which we have to get rid of is a gas, that heated gases rise, while heavy metallic masses fall, and that we must not expose the ore to the action of fresh oxidizing air, it is evident that the blast should enter at the bottom of the furnace, and the whole charge be heated from below upwards.

These arrangements are common to the most primitive and the most modern blast furnaces; from the simple clay box still used in India among the hill tribes of the Ghats, which is but 2 feet high and yields but 5 or 6 lb. of iron at a charge, or the excavated banks of clay of Tendukera, up to the modern gigantic fire-towers, reaching in some cases to above 100 feet in height, with an internal capacity of 30,000 cubic feet.

In all of these the ore with its fuel, whether charcoal, coke, or coal, is charged from above, and the blast applied below to the already heated fuel. Taking the simplest case first, where the ore is a pure oxide of iron and the fuel and reducing agent is charcoal, the action is not difficult to understand.

First, the air of the blast strikes the heated charcoal, its oxygen combining with it, and by such combination or combustion evolving great heat. The result of such combustion where there is an excess of carbon is carbonic oxide, a gas itself combustible, i. e. hungering for more oxygen when heated. This gas passes upwards, and does the double work of heating the upper layers of charcoal and assisting it in taking the oxygen from the ore. The ore is thus reduced to metallic iron, which, according to the quantity, temperature, and condition of the carbon, will form either a compound of iron and carbon or a nearly pure iron.

In the first case, it will run down to the bottom of the furnace in a liquid state. In the second, it will form a soft pasty spongy mass called a "bloom," which requires hammering or squeezing to render it compact iron.

In the simple case above described, where the ore is pure and the fuel a pure charcoal, the fusible compound of iron and carbon will be steel, varying in hardness and brittleness according to the quantity of carbon that it contains.

With such materials it is easier to make steel than to make soft iron, and thus I venture to suppose that steel was invented before iron, or simultaneously with it; as in the first rude efforts the result would be very variable, a hard steel, a mild steel, or actual iron being produced, according to the proportions of ore and charcoal, the depth of the furnace, and the force of the blast.

The first iron-makers—the men of the bronze age—knowing that bronze can be hardened or softened by heating and cooling it either slowly or quickly, would naturally try whether their newly obtained metal possessed the same excellent property, and thus it is not at all surprising that the earliest and rudest workers of iron were not only makers of steel but acquainted with its invaluable capability of hardening and tempering. Historical records tell us more of ancient steel than of ancient iron, and the native Hindoo and Burmese iron-makers of the present day, as well as those of Borneo, Africa, Madagascar, &c., all produce fine steel directly from the ore, and usually more easily and cheaply than they can make malleable iron. The reasons why the modern English ironmasters, with all their engineering and chemical science, fail to do this, will be explained hereafter.

We now come to the more complex problem of British iron and steel manufacture, the complexity being an inevitable result of the composition of the materials used. The supplies of ores consisting only of pure oxides of iron are far too small for modern requirement, and the same may be said of the pure fuel, i.e. charcoal. We have been compelled to use very complex poor and impure ores, and a fuel which actually conveys damaging impurities to the iron. It is a remarkable and suggestive fact that the two districts, South Staffordshire and Cleveland (Yorkshire), which are the largest iron-making centres of the world, are just those which are supplied with the worst iron ores that have ever been commercially worked.

What then are the impurities of ore and fuel which present these new difficulties? First, as regards the ore. Instead of unmixed oxide or carbonate, we have mixtures of these with earthy matter, such as clay, sand, &c.

The ores of the metals are usually found in veins that intersect the strata, or masses of rocks, in the shape of cracks or chasms, filled up by injection, sublimation, or some unexplained process of deposition that occurred since the rocks around them were settled in their present places. Not so with the common British iron ores, which are for the most part sedimentary deposits, interstratified with the rocks in which they lie, sometimes occurring as continuous beds or strata, in other cases as nodules and irregular deposits. Thus, whether deposited in the bed of a sea, lake, estuary, or river-mouth, the iron oxide or carbonate is intermingled with more or less of the other matters which the water held in suspension. Many of our iron ores are found in the form of nodules having an organic nucleus in the centre; and when this nucleus, as often happens, is a fish or other animal high enough in the organic scale to have phosphate of lime as the basis of its skeleton, a serious impurity is introduced in the form of phosphoric acid. This is the chief defect of the ores of the great Cleveland iron-making district. It presents very serious difficulties; but there are Yorkshiremen as well as phosphates thereabouts, and hence the difficulties have been overcome.

Besides containing positively mischievous impurities, these earthy argillaceous ores of iron are very poor. Instead of 60 and 70 per cent. of iron, like the ores of the primitive workers, they contain little more than half of that quantity, or from 30 to 40 per cent. To understand the process by which the earthy impurities of the ore are removed, the reader must note that when an oxide of iron or of any other common metal is heated with silica (sand, flint, quartz, &c.), a combination takes place, and a silicate or glassy compound of the metal is formed. Thus if we were simply to heat with charcoal, in the manner already described, a poor earthy iron ore containing much free silica, we should obtain, not metallic iron, but a dark-coloured, fusible iron-glass or silicate of iron—a brittle and worthless compound.

The obvious remedy for this is to find some substanc which, under the circumstances existing in the furnac will combine more readily than oxide of iron wit silica, which will appropriate the silica, and thereb prevent it from combining with the iron. There a many metallic oxides that will do this, but the iron maker requires one that is abundant and cheap, an this he has found in lime, or the oxide of calcium. B heating lime as well as carbon with the silicious iro ores, a lime-glass is formed rather than an iron-glas This lime-glass readily fuses, and carries with it by solvent and washing action most of the clayey an other earthy impurities of the ore. The lime thu used is called by the workmen a "flux," and the complex glass formed by it the "cinder." *

It must be understood that the iron-workers w

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* In chemical and metallurgical treatises this is usually nominated "slag," but in this case the workman is more cor and discriminative in the use of words than the man of scie Most of the technical terms used by our miners and metal-wor are of Scandinavian origin, and in the use of the terms "s and "cinder" the old-fashioned iron-workers retain their ori etymological signification. "Slag" is the unaltered Scandin for a blow or stroke, "cinder" comes from *sinnern* or *sint* trickle or drop, and the words are used accordingly,—" to describe those silicates, &c., that are squeezed from the when *struck* with the hammer, while "cinder" is applied melted matter which drops or flows from the fire, wheth that of a blast, a puddling, or any other form of furna the distinction is of chemical and practical as well as gical signification, I shall use these terms with the wo meaning.

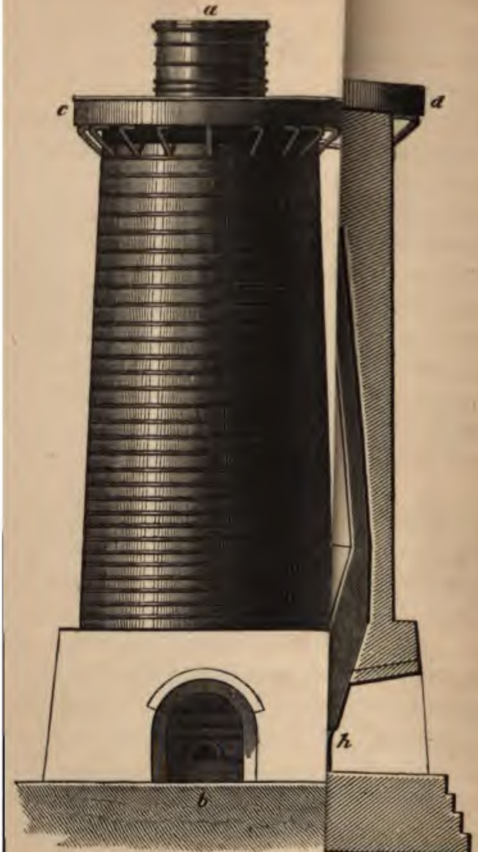

Fig. 1.

first used lime as a flux were unacquainted with the above-stated chemical principles of its action, though they must have learned its properties in relation to their own particular requirements by following rudely the inductive method of observation and experiment which, carried out more systematically, has led to the great results of modern science.

The present blast furnace is a hollow tower varying from 30 to more than 100 feet in height, with an internal capacity from a few hundred up to 30,000 cubic feet. Externally it varies considerably in form, in some cases being conical, with wide-spreading base due to great thickness of lower walls and foundation; in others, especially those of most recent construction, a nearly cylindrical pillar of brickwork braced together with iron bands, and resting on a base of stone or brick, or both combined. Figs. 1 and 2 represent in elevation and section a furnace of this kind, erected at Oaken Gates by the Lilleshall Iron Company.

The variations of external form are of small importance, and depend considerably upon the nature of the ground upon which the furnaces are erected, and the relative cost of the different materials on the spot.

The internal form is, however, of considerable importance; and though varied to a certain extent, that which is drawn in the section, Fig. 2, may be taken as typical. Following it in the order that its contents travel, viz. from above downwards, we find that from the summit down to about the level of the floor of the surrounding gallery (*c d*) it is cylindrical; from this point it gradually widens till we get about two-thirds of the way down, and after this it contracts more rapidly till we reach the base.

The cylindrical portion at the top, which is really but a chimney, and does not exist at all in some furnaces, is called the "tunnel-head." The upper cone from the bottom of the tunnel-head to the widest part is the "stack." This widest part is the "belly," which would be better if more rounded than in the figure; and the lower cone down to the tuyere-holes (*h h*) the "boshes," below which are the "hearth" and the "crucible," wherein the melted metal accumulates until the furnace is tapped. The "throat" (*e e*) is where the charge of ore, fuel, and flux is tipped in from barrows through the arches shown in the figure.

The whole of the furnace is lined with fire-bricks composed of the most refractory matter within reach; the thickness of this lining, or "shirt," increasing downwards as the heat increases.

The gallery, or "charging plate" (*c d*) is shown in Fig. 1, connected with a hydraulic lift, by which the barrows of ore, &c., are raised to the level of the throat. Many other devices are used for this purpose, such as a cage with guides, wound up like a colliery cage, or inclined planes; while in hilly places advantage is sometimes taken of a precipitous valley or hollow, aided by some amount of excavation, to build the furnace with its throat only just reaching the generally available level. Where such vast quantities of material are used as in the blast furnace, economy of haulage is a most important practical consideration.

The tuyere-holes (*h h*) are perforated through the walls of the hearth, and vary from two to six in number. Into these are set the tuyeres or blast pipes, which are iron tubes, the nozzle ends surrounded with an outer case through which water is kept flowing.*

Until 1828 only cold air was used for blast furnaces; but at that date Mr. Neilson, of Glasgow, patented his very important improvement of the hot blast. With very few exceptions the hot blast is now generally used. It effects a very considerable saving of fuel, and may be ranked with the most important improvements in iron-making. The air from the blowing machine is driven through coils or convolutions of heated iron pipe, and thus raised to a temperature varying from 300° Fahr. to 700° or 800°. The economical value of the hot blast is shown by the fact that during the first six months of 1829, when the cold blast only was used at the Clyde ironworks, each ton of iron required the coke from 8 tons 1¼ cwt. of coal for its production, while during the corresponding period of the following year the same work was done with 5 tons 3½ cwt., the blast being only raised to 300°. In the Swedish blast furnaces, with the blast at 482°, the saving of fuel is estimated at 33 per cent.

In most modern furnaces the blast is heated, and the steam of the blowing engines is generated, by utilizing the gases, which formerly belched forth a great waving blue flame from the top of the furnace. In these cases the tunnel-head (*a e*, Figs. 1 and 2) is absent, and a funnel, or a cup and cone are inverted into the throat of the furnace. The diameter of the inverted cone or cup being somewhat less than that of the interior of the furnace, the charge is tipped all around it, and lying above, closes the throat sufficiently to cause most of the combustible gases to pass up the funnel and the tube, as shown by the arrow in Fig. 3. The tube is bent down, and conveys the gas to the blast heater and the engine boilers. There are other arrangements for effecting the same purpose, but I have selected the simplest for illustrating the general principle upon which all are constructed.

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* The tuyere is of course double, an inner tube for air, an outer one for water.

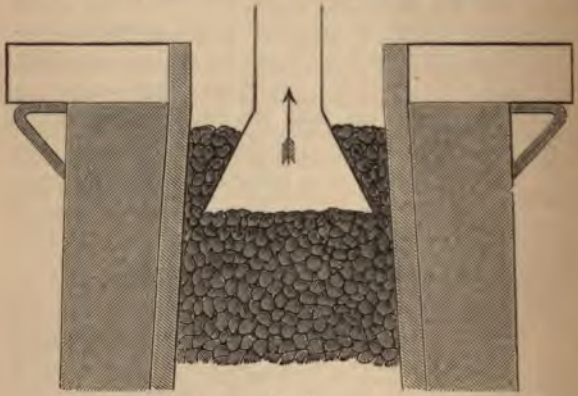

Fig. 3.

Supposing the blast furnace to be built, sufficiently dried, and provided with all its necessary appendages, the mode of beginning to work it, or "blowing in," is as follows: From 10 to 20 cwt. of firewood in large pieces is first laid at the bottom, to a height of 3 or 4 feet; on the top of this is piled 5 or 6 tons of coke, and above it regular charges of coke (or coal and coke), lime, and ore, the quantity of ore or "burden" being made very light at first. When the furnace is thus filled to about one-third of its height the wood below is ignited. As soon as this mass is in sufficiently active combustion for the upper surface to fairly burn, the charging is resumed, with a gradually increasing burden of ore, until the furnace is about two-thirds full. When the combustion has fully penetrated this additional mass, the regular charge is added, and the blast turned on to about half or two-thirds of its ultimate quantity; the furnace is thus gently heated for a day or two, after which the full blast is turned on and regular working commenced.

The charge varies of course with the nature of the ores that are used. In ordinary work in this country the rich and poor ores are so mixed that they shall yield nearly half their weight of pig iron, and in such cases the charge consists of about one part of limestone and two of coke, or of mixture of coal and coke, to three parts of ore. These are added alternately, and gradually descend. As they proceed downwards a series of changes occur, finally resulting in the production of molten pig iron and molten cinder floating above it. These changes are somewhat complex in their details, and although they have been very industriously studied of late, are but approximately understood. The general nature of the action may however be safely described in outline as follows:

First of all the charge is simply heated or roasted.

The ore thus loses any water that it may contain, and afterwards, should there be any carbonate of iron, the carbonic acid is driven off. If coal is used, this is coked at the same time. The limestone is roasted in a similar manner, and as it proceeds downwards, it reaches a zone of limekiln temperature and is there decomposed and red-hot quicklime formed.

But the iron ore is not *merely* heated as it would be in a crucible or oven, it is at the same time subjected to the action of the gases produced in the hotter regions below, and which are continually rising amidst it. The most important of these are carbonic oxide, which is carbon supplied with but half its meal of oxygen, and when thus heated still hungering for more; hydrogen and hydrocarbon gases, also hot and greedy for oxygen; and, besides these, cyanogen, a compound formed by the union of the carbon of the lower fuel with the nitrogen of the air. This (whether alone or in a probable state of combination) is, like the others, a powerful deoxidizing or reducing agent, and thus the reduction of the oxide of iron in the iron ore commences as soon as its water and carbonic acid are driven off, i. e. when it reaches a dull red heat.

This reduction is described by Mr. Lowthian Bell as commencing even before the limestone has lost its carbonic acid, but I doubt whether it is *completed* until the whole of the limestone is decomposed. To express this, I have taken a slight liberty with the annexed copy of Mr. Lowthian Bell's diagram (Fig. 4) by bracketing together the second and third zones and carrying the "reduction" through both.

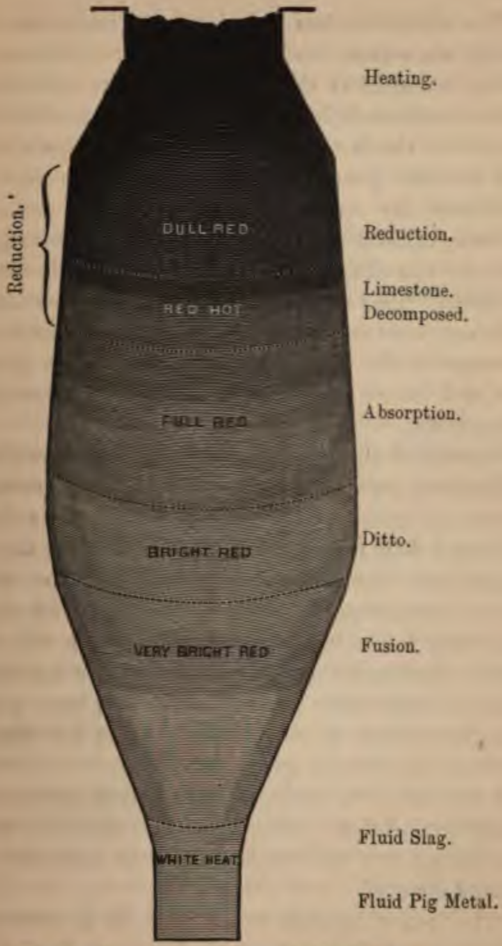

Fig. 4.—Temperature Changes in Blast Furnace.

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The reduction thus completed, we have iron in a spongy state disseminated in small particles among the earthy materials of the ore. Here then we have the iron actually made, before the charge has travelled half-way down the furnace. If the ore was a pure oxide, and our fuel pure carbon, we might stop here and withdraw the spongy iron or "bloom" from the furnace, hammer and roll it at once, thus saving not only the rest of the blast furnace work, but also that of puddling. This is just what the primitive iron-makers did, and what is still being done in the small blast furnaces of the Oriental iron-makers of the present day, and in the Catalan furnaces of Spain, south of France, &c.

Instead of this simple proceeding, the particles of reduced or separated iron have now to be rendered impure, in order that they may become fusible and thus separated from the earthy matter with which they are entangled. This is effected by its combination with a certain proportion of carbon, and by the union of the lime with the silica of the ore, forming a still more fusible glass in the cinder. If only these combinations took place, the blast furnace would be a more perfect instrument than it is; but such is not the case, for sulphur, phosphorus, and silicon, &c., also unite with the reduced iron, while in this heated, spongy, and finely divided state. All of these are mischievous, and the phosphorus and sulphur are only separable with great difficulty.

The iron thus adulterated proceeds downwards to hotter and hotter regions, until fusion, first of the cinder and then of the impure iron, takes place at the "boshes," i. e. the narrowing or lower funnel-like portion of the furnace, down which they slowly trickle and accumulate at the bottom. The impure iron being the heaviest, the cinder floats upon its surface and is useful in protecting it from oxidation by the blast.

The hearth or crucible into which the fused silicates and the metal finally sink is closed all round at its lower part; but on one face, that of the "dam" and "dam plate," it has an upper opening or groove over which the cinder, which has five or six times the bulk of the iron, continuously flows, and is received into convenient moulds and wheeled away to form the great "spoil banks," that are such characteristic features of the dreary landscape of an iron-making district.

While this is going on, workmen are employed in shaping the moulds into which the fused impure iron is to run. These consist simply of two or three main furrows or channels made in a large bed of sand, from each of which, branches 4 to 6 feet long are made at right angles. The main furrows are called the "sows," and the short branches the "pigs."

As already stated, the fluid cinder flows over the upper edge of the fire-clay dam and its outer protecting iron shield, the dam plate. Lower down, a narrow vertical slit is pierced through the dam. This is rammed with sand while the crucible is filling. The main sow communicates with this opening, and when the crucible is sufficiently filled, the plug is struck out by means of long iron bars and the glowing liquid flows along the sows and into the pigs, forming, when cooled, "pig iron."

What, then, is pig iron? The following, which is the average result of analyses I have made of thirty-three well-known brands, affords a fair representation of the composition of the *better* qualities of British pig iron. I say "better" qualities, because the pigs analyzed are those used at the works of Sir John Brown and Co., Sheffield, where they are selected for the manufacture of high-class finished iron:

Combined Carbon	0·916	Total Carbon = 2·834
Graphitic Carbon	1·918	
Silicon	1·810	
Phosphorus	0·332	
Sulphur	0·253	
Manganese	1·280	
Titanium	0·073	
Iron by difference	93·418	
	100·000	

The analyses upon which the above average is based were made commercially for practical purposes, and therefore the small traces of other substances not affecting the practical quantity of iron, such as calcium, copper, &c., were not looked for, and thus the percentage of iron by difference is slightly in excess. The titanium was only determined in a few cases where expected, but its average is included, as it is fairly representative.

The carbon is stated separately as combined and graphitic. This is a very important distinction, though sometimes neglected in such analyses. If we have two samples of pig iron containing equal total proportions of carbon, and alike in other respects, but differing only as regards the *condition* of the carbon, the appearance and properties of the pig will be curiously different.

Let us suppose two samples A and B, each containing 3 per cent. of carbon. In A the carbon is graphitic or uncombined, in B it is combined. The appearance of A will be dark, granular, and porous, and careful examination will reveal small glittering scales of plumbago dispersed among its pores. It will be comparatively soft, and easy to be filed or drilled. B will be brighter and of almost silvery colour, very hard, compact, and crystalline. A is what the workman calls "grey pig," B "white pig." The gradations between these are distinguished in the trade by numbers, beginning with A as No. 1. Intermediate pig, wherein the combined and uncombined approach equality, is called "mottled pig."

If the white pig is subjected to the action of an acid solvent, such as dilute nitric acid, it dissolves into a dark-coloured liquid. If the grey iron is similarly treated, the solution is of a light greenish colour and scales of graphite remain undissolved. These, when separated, washed, and dried, stain the fingers and otherwise display the properties of common plumbago. The greyest pig, and richest in carbon, often contains cavities, varying from minute pores to holes in which a finger may be thrust, from which beautiful scales of this graphite, or "kish," as the workman calls it, may be collected mechanically as with the point of a penknife.

The cause of the difference between the conditions of the carbon in grey and white iron has been the subject of much discussion, and is still but imperfectly understood. The heat of fusion and rate of cooling have evidently much to do with it. If grey iron is melted at a high temperature, much of the graphitic carbon combines, and upon cooling again the iron becomes mottled or white. On the other hand, some of the most highly carburetted of white irons, such as the spiegeleisen used in the Bessemer process, deposit beautiful scales of graphite when melted.

Speaking generally, we may regard the influence of the carbon impurity of the pig iron as rendering it more fusible, and when combined, more hard and brittle.

Silicon, which has so many curious resemblances to carbon, affects iron in nearly the same manner.

Both carbon and silicon are easily removable from pig iron. When pig which is rich in both is melted in free contact with oxygen, the silicon is first attacked, and until its quantity is considerably reduced (down to about one-third per cent., according to my own experiments), it monopolizes nearly all the oxygen, and the carbon remains almost intact. After this the oxidation of the carbon proceeds more and more rapidly until it is reduced to about one quarter per cent., when the iron itself begins to burn if the supply of oxygen is abundant and the temperature high.

If pig iron contained no further contamination than the silicon and carbon, it might thus be easily refined to the conditions of malleable or wrought iron, which is iron in its nearest practical approach to purity.

Next to the silicon and carbon, the most easily removable impurity is the manganese, which is readily oxidized, and its oxide combines with the silicon. Some believe that manganese improves both iron and steel.

There is no doubt whatever respecting the mischievous influence of the sulphur and phosphorus. Until lately sulphur was considered the greatest enemy, but most iron-makers now agree in regarding the phosphorus as rather the worst. It certainly is a very remarkable fact that so small a quantity as the one-thousandth part of phosphorus will make all the difference between good and worthless steel, i.e. between steel fit for making tools and that which is not to be trusted for even the coarsest purposes to which steel is applied such as the manufacture of rails or ploughshares. The phosphorus renders the steel brittle and incapable of standing a vibratory shock, such as that to which the teeth of a file or saw or the edge of a chisel is ordinarily subjected. Steel containing only $\frac{1}{2000}$ part of phosphorus is unfit for the best kind of cutlery, or with $\frac{1}{1000}$ part is worthless for any tool-making purposes. The more carbon the steel contains, the less phosphorus it will bear, and, in accordance with this, wrought iron, which is nearly free from carbon, will bear a larger quantity than any kind of steel. The brittleness due to phosphorus is not displayed, when the iron or steel is heated, but only when cold, and hence such steel or iron is called "cold short."

Sulphur also produces a brittleness, but it shows itself chiefly when the iron or steel is red hot, and hence is called "red shortness." A given quantity of sulphur does less mischief to steel than the same proportion of phosphorus, but iron used for forgings is the most sensitive to the injurious effects of sulphur.

The difficulty of removing the last two or three-tenths per cent. of either sulphur or phosphorus is very great. Large proportions of either are easily brought down to about three-tenths per cent., but as we go on reducing the quantity, the tenacity with which this small residuum adheres to the iron goes on increasing.

An enumeration of the various unsuccessful and doubtful projects for removing the last traces of these impurities would occupy volumes; I must therefore confine myself here to the only one which has been sufficiently successful to be adopted in general use., viz. the puddling process invented by Mr. Cort. So important have been the results of this invention, that I may venture to say that the only civilized human being of his own generation who was not benefited by Mr. Cort's invention was Mr. Cort himself; and the only family of the succeeding generation who were not still greater gainers by it were Mr. Cort's own family, for they, like their father, would probably have been more prosperous had he never made his great invention. Their history, like that of Dud Dudley, who taught his fellow countrymen how to smelt iron with pit coal, is a miserable and disgraceful one, and too long to be told here.

The ordinary process of puddling consists of melting the pig in a flat-bottomed reverberatory furnace lined with some compounds of iron and oxygen, stirring the melted mass until its impurities are separated, partly as gaseous compounds and partly as liquid cinder: then collecting together the infusible iron and forging it into slabs, bars, &c., as may be required.

The construction of the puddling furnace will be understood from the following figure, a vertical section along the middle showing (*f*) the fireplace, (*b*) the bed of the furnace on which the pigs are melted and puddled, (*br*) the bridge over which the flame from the fire plays and reverberates from the roof, (*fl*) the flue which may communicate directly with a stack, or be carried under steam boilers to utilize the large supply of residual heat, (*pppp*) the iron pillars which support it, leaving air cavities below. The whole structure excepting the flue is encased in iron plates, which are strapped together by iron rods.

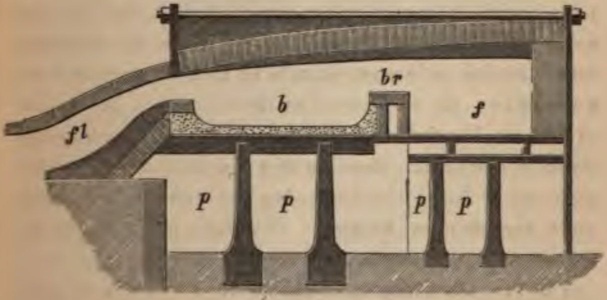

Fig. 5.—Vertical Section through a Puddling Furnace.

The puddler's mode of proceeding is as follows: The fire being lighted, and the roof, the walls, and floor of the furnace cavity being made red hot by the flame which plays over the bridge and strikes against them, he carefully "fettles" his furnace by throwing in and plastering the bed and sides with ground oxide of iron which has been worked with water to the consistence of common mortar. The best material for "fettling" is red hæmatite, but cheaper materials are commonly mixed with it or used in its stead. "Bull dog" is the most important of these, and is made by roasting refuse cinder or impure silicate of iron in an oven like a limekiln. By such roasting the silicate of protoxide of iron is changed into sesquioxide of iron and uncombined silicic acid. Besides this wet fettling, a certain quantity of loose "hammer slag" is commonly thrown upon the furnace bottom. We shall see the use of these things presently.

The furnace being thus prepared, the lumps of pig iron are thrown in, the door closed, the fire made up, and dampers raised to obtain as much heat as possible. An ordinary charge is 4 cwt. to 4½ cwt. of pig, usually 4¼ cwt. The time required for melting varies considerably, according to the composition of the pig and the state of the furnace, though from thirty to seventy or eighty minutes may be quoted as a fair range.

Two men work at each furnace, the puddler-in-chief and his assistant or under hand. The work, which is very severe, is divided between them, the puddler taking *that portion* which demands the greater amount of skill. The result is weighed when finished, and they are paid accordingly.

During the melting the under hand turns over the lumps and stirs the liquid with a long iron rod. When the melting is completed, a similar iron rod or bar, flattened and bent at the working end, is used, and the stirring is conducted more vigorously. This bar is called a "rabble," and the stirring process "rabbling."

Melted pig presents some curious appearances. At first the surface is agitated by the bursting of small bubbles. This agitation, at first merely superficial, gradually deepens, and finally the whole mass is seen to be seething and heaving, or spirting up a series of jets or bubbles, which, as they burst, throw up flashes of bluish flame, composed mainly of burning carbonic oxide. This is what the puddler calls the "boiling" stage, and it is now that the rabble is applied with the greatest vigour, while the towel or "mop" round the puddler's neck is soaked with the perspiration he continually wipes from his face. The chief puddler goes on until exhausted, and the under hand without delay then takes his place. As the rabble becomes softened by the heat it is plunged into an iron tank of water and exchanged for a cooler one. The boiling increases, the melted mass thickens, assumes a gruelly appearance and swells considerably, often overflowing by the rabble hole. From gruelly it becomes decidedly granular, and is seen to be no longer a homogeneous liquid nor even a smooth paste, but a liquid thickened with sandy-looking solid particles. The puddler describes this as "coming to nature." The solid particles are the comparatively infusible iron, and the liquid is the compound of silicates, &c., called the cinder.

The puddler carefully *feels* the condition of the mixture, and vigorously brings those portions which are less advanced into the most active portion of the furnace, groping about the bottom, sides, and corners of the furnace to prevent adhesion of the solid iron. When it has fully come to nature, i. e. when the separation of the silicon and carbon and consequent infusibility of the iron is sufficiently complete to render the distinction between iron and cinder quite unmistakable, the puddler commences gathering the solid particles together into balls, or "balling up." Three or four of such balls are commonly made from each heat. They are grasped by powerful tongs, placed in an iron truck, and wheeled off to the hammer, where they are welded into a coherent solid mass. The tilt hammer was formerly used for this purpose, but it is now nearly superseded by the steam hammer.

"Squeezers" are sometimes used instead of the hammer; the puddled ball is thrust into a mouth formed by circular corrugated jaws, the inner one of which rotates and carries the ball with it into a gradually narrowing space, until it completes the circuit and comes out a cylindrical mass of coherent iron. Other forms of squeezers are simple gaping jaws that open and close by a hinge, like the jaws of an animal, and have notches corresponding to teeth. Where large pieces of iron are required, several balls are welded together as they come from the puddling furnace. The steam hammer has a great advantage over the tilt hammer, as the latter must always fall with its full weight, while the steam hammer may be "humoured" with any degree of delicacy, even to cracking the top of an egg in an egg-cup. Certain qualities of iron, which would crush into fragments under the tilt, may with care be welded into slabs by the steam hammer.

I now come to the theory of puddling, which is still a debatable subject. It has been described as merely a process of oxidation effected by the air which plays along with the flame upon the surface of the shallow pool of melted metal. This, however, is in a double sense a very superficial explanation. It leaves out all the phenomena of boiling and the jets of carbonic oxide which are so remarkable and characteristic. There can be no doubt that oxidation is rapidly proceeding, and is an important element of the puddling process, but this oxidation is not wholly, nor even mainly due to atmospheric oxygen. The oxygen that is the most effective in puddling is that which is evolved from the fettling. The sesquioxide of iron used for this purpose is reduced to protoxide, and even to metallic iron, and the oxygen evolved passes *through* the melted pig, combining with its silicon to form silicic acid, which combines with protoxide of iron, but not with sesquioxide. This oxygen also combines with the carbon and forms the jets of carbonic oxide already described. I have often watched the puddler very carefully, and have observed that he does not merely stir the liquid as a cook whips an egg, excepting at one particular stage, viz. when the boiling is nearly completed and the iron is coming to nature. Previous to this, when it is desirable to accelerate the oxidation or boiling, he continually scrapes the bottom of the furnace with the bent end of his rabble. I have learned to respect so profoundly the curious store of illiterate scientific knowledge possessed by the puddler, that I always seek a reason for everything he does. The evident, though unexplained, reason for his careful scraping at the bottom, before there is any risk of adhesion, is, that he is scrupulously bringing fresh surfaces of the melted pig in direct contact with the surface of the fettling, that it may have the full benefit of its oxidizing action, and that the top deoxidized film of fettling may be removed.

So far, then, there is no difficulty in explaining the removal of the silicon, carbon, and manganese. We find the silicon combines with oxygen in the silicates of the cinder, and we see the oxidation of the carbon in the flame jets of the boiling. The oxide of manganese combines with some of the silicic acid. But I have already stated that mere oxidation will not remove the small but mischievous residuum of sulphur and phosphorus. The experience of the Bessemer process and other devices dependent upon mere oxidation has now rendered this statement incontrovertible. But puddling *does* remove sulphur and phosphorus sufficiently to produce good merchantable iron from pigs abounding in both of these evil impurities. How does it effect this?

This question has never been satisfactorily answered.

Mere oxidation was tacitly accepted as explaining all the phenomena of puddling, until the facts revealed by the Bessemer process effectually refuted the assumption. I have endeavoured, by carefully watching the proceedings of the most successful puddlers, to find a better explanation. It is known that much of the sulphur and most of the phosphorus which are removed by puddling, pass into the fusible silicate or "tap cinder," and Dr. Percy has shown reasons for suspecting that a "liquation," or sweating out of the more fusible sulphides and phosphides may occur when the iron is solidifying, or "coming to nature." I believe that this is correct, but it is not all, and that the essential efficacy of the puddling process, as regards sulphur and phosphorus, is, that it consists in a *washing* of the granules of iron in the fusible cinder; that the fusible sulphides and phosphides, in accordance with the general laws of fluid diffusion, have a tendency to mix with the liquid cinder, and that the puddler, by violently agitating the solid particles of the iron amidst the cinder, avails himself of this tendency to wash away the phosphides and sulphides that exude from the surface of each little particle of iron. I was led to this conclusion by the change of action which the best puddlers adopt immediately the iron begins to come to nature. Instead of leisurely rubbing or groping the hook of his rabble along the bottom of the furnace backwards and forwards, he commences a furious stirring of the whole mass. Using the sides of the rabble hole as fulcra, he works the rabble violently from right to left like a paddle, and evidently attaches the greatest importance to the vigour of this performance. My own observations of the effect upon the quality of the iron of extra effort or neglect at this stage fully confirm the puddler's belief.

By way of summary, I may describe the puddling process as an oxidation of the silicon, carbon, and most of the manganese of pig iron, and a washing out of the greater portion of the phosphorus and sulphur by the fusible silicates forming the cinder.

I should have added that every puddler knows that without a good "bath" of fusible cinder he cannot get good iron from impure pigs, and when his pig is "dry," i.e. deficient in silicon, he adds a good quantity of silicate in the form of hammer slag, or tap cinder. He prefers the slag, and chemical analysis reveals his reason, for it contains far less of phosphorus and sulphur than ordinary tap cinder, and hence washes out these impurities more effectually from the iron.

The silicates are otherwise useful: they assist in protecting the granules of iron from the oxidation which in the advanced stage would be mischievous. This risk of oxidation is the greatest when the puddler is collecting the granules into a ball, during which time his furnace-door is necessarily open, and the glowing iron is thus liable to exposure to the air. A coating of oxide upon the granules of iron would prevent their welding together under the hammer or squeezer. The puddler is well aware of this, and takes very skilful measures to prevent oxidation or "cutting," as he sometimes calls it. He closes his dampers, throws fresh coal not only on the fire but also on the air-ways of the fire, in order that he may have a reducing or deoxidizing flame. He makes up and places the ball not on the handiest place, viz. opposite the furnace-door, but quite on one side of the fire-bridge. There it stands to await, if necessary, its turn to the hammer, enveloped in a lurid sooty flame which affords the best possible protection from atmospheric oxygen.

The puddler has too often been unjustly censured by merely book-learned critics, who have pointed to the dense volumes of black smoke issuing from his furnace chimney as evidence of his ignorant wastefulness of fuel, and lecturers have come all the way from London to the Black Country to put him right. In this case the ignorance is all on the side of the learned men, and the true scientific knowledge with the black-faced illiterate puddler, who has acquired his knowledge by his own unaided application of the Baconian method of inductive research. He has observed, experimented, generalized, and deductively applied the principles thus induced, all without ever having heard of any other Bacon than that which is salted, and without being able to expound his knowledge in any other form than practical lumps of malleable iron.

Again and again I have carefully watched the puddler's furnace during the whole course of his operations, and have found that (except at the moment of firing) there is no black smoke to be seen so long as the coal is required *as a source of heat*, the smoke only pouring forth when the puddler is using the hydrocarbon of his coal as a reducing agent, i. e. when his business is not to melt or to burn, but *to prevent burning.*

A great deal of ingenuity has been expended on efforts to puddle iron by machinery, but with very limited success. Many of the inventors have started with a false theory of puddling. They have assumed that it is a mere matter of stirring or agitation requiring to be done in a regular and vigorous manner. If such were the case, puddling by machinery would be one of the simplest of mechanical problems. If the puddler were, as so many suppose, a mere muscular machine, his muscles might at once be superseded by the steam-engine. A score of machines have been tried, and all have failed. A certain amount of success has been attained where the machine has been applied to *assist* the puddler by driving the rabble which the puddler holds in his hand, and guides by his intelligence. One of the more recent of these is the rotating rabble of Dormoy, the principle of which will be easily understood by anyone who has had his hair brushed by machinery. Above the furnace is a rotating shaft upon which a pulley is fixed, with an endless band hanging loosely down in front of the furnace, and of course travelling as the pulley rotates. The puddler's rabble has also a pulley attached, which he rests upon the lower part of the band when required. It then revolves, and the end being shaped as a rude Archimedean screw, or a flat paddle according to the work required, the puddler has only to swing it to the place where agitation is required, and his stirring or groping efforts receive important aid from the rotatory agitation with which they are accompanied. The weight of the rabble is supported by the band, and thus a much heavier rabble may be used. One advantage of this is, that it is not so rapidly heated. I have seen good results obtained thus, but the puddlers complained of excessive wear and tear of the furnace bottom.

The mechanical device which has recently attracted the greatest attention is the rotatory puddling furnace reintroduced and improved by Mr. Danks and still further improved by Mr. Crampton. Here it is not the rabble, but the furnace itself which rotates. In spite of very sanguine hopes and promises and the reports of successful performance, I am still doubtful of its ultimate and general success. It rolls and agitates most efficiently; it brings the melted pig well in contact with the fettling; but it lacks the puddler's intelligence, and supplies no efficient substitute for it. With a suitable quality of pig it may do the work of an inferior puddler; but I cannot understand how any mere rotating drum, with even the most skilful arrangement of internal splashers, can effect those adaptations of operations to requirement, which constitute all the difference between skilful and clumsy puddling. It must be noted that there are puddlers and puddlers: that with the same pig, fettling and fuel, one will produce an iron that is just merchantable for ordinary purposes, another will turn out an iron of fine quality. To make iron of some sort and plenty of it is a comparatively easy task, but to produce a fine quality of iron from common or inferior pig is a very difficult problem, which none but our most skilful puddlers have yet succeeded in practically solving.

I should add that puddling furnaces are sometimes made double, with doors opposite to each other, and worked from opposite sides by two sets of men. These furnaces take double charges. In some works a considerable saving of time and fuel is effected by charging the puddling furnaces directly from the blast furnaces, the fluid metal being poured down channels or gutters made for the purpose. In these cases, of course, special arrangements are demanded to adapt the blast furnace for frequent tapping and the drawing off of small quantities at one time, and the puddling furnaces have to be arranged about the base of the blast furnaces. I have seen this mode of working successfully carried on with double puddling furnaces at the Chillington Iron Works, near Wolverhampton. As the cost of fuel increases, it is likely to be more commonly adopted.

The subject of puddling must not be dismissed without a few words on "physic." This is the name which the puddler gives to certain chemical substances which are occasionally thrown into the furnace, either before or after melting. The amount of mystery which commonly enshrouds these admixtures, and the solemn and knowing manner in which the paper packets are thrown into them by the physic man, are often quite grotesque. Each particular physic is supposed by its proprietor to be a profound secret, is locked up in a strong box or shed, and jealously guarded. I have seen many of these, and have had several sent to me for analysis. All were alike: common salt or agricultural salt, either used without admixture, or more or less disguised with soot, sand, iron scales, washing soda, &c. It appears that small quantities of common salt or other chlorides are in some cases really beneficial. Had this subject been investigated instead of mystified, I have no doubt that some very useful and practical knowledge might have been obtained; as it is, it would be unsafe to venture beyond a general speculative surmise that these chlorides do something towards the removal of sulphur, and possibly of phosphorus, in the form of volatile compounds.

The process recently introduced by Mr. James Henderson, of the United States, and known as "the Henderson process," is the only purely chemical device I have yet seen that removes phosphorus and sulphur as the puddler does. Mr. Henderson mixes powdered fluor-spar (fluoride of calcium) with oxide of manganese, cheap iron ore, such as ilmenite, or even powdered fire-brick, and places about 1 cwt. of this mixture on the bottom of the hot puddling furnace; after which an ordinary charge is added, and melted in the usual manner. If this is now left, *without any puddling*, it gradually rises to even a more violent state of boiling than is attained by the puddler. The jets of flame are yellowish and very abundant. The iron rapidly comes to nature, and in less time than is required for ordinary puddling it is completely made, adhering more or less firmly to the furnace bottom. I have carefully watched this process, and analyzed the iron and mild steel made thereby, with much surprise at the effectual removal of the sulphur and phosphorus, but more particularly of the latter. The reaction of the fluoride is evidently most powerful, and the only doubtful point relative to this process is whether it attacks the iron and diminishes the yield. To settle this question it must be conducted in a furnace especially adapted to itself, and upon iron run directly from the blast furnace.

As already stated, the ball of iron which the puddler collects, and which, as he grasps it with his tongs, appears like a mass of red-hot sponge, is placed under the tilt or steam hammer, or passed through a squeezer.

The object of this is twofold. First, to weld together the loosely coherent particles of iron, and, second, to squeeze out from between them the still adhering fusible silicates. The resemblance to a sponge is made very manifest when the ball is seen receiving its first stroke from the steam hammer, for as it is crushed down, the liquid silicates ooze from it just like water from a saturated sponge. At each successive blow the ball becomes more and more solidified, and the amount of oozing liquid gradually diminishes as the block of iron hardens, while the blows, at first quite silent, become more and more resounding. After the second or third blow the red-hot liquid is dashed out so violently that it is dangerous to stand within duelling distance of the hammer; and the "shingler," who turns the iron about and places it under the hammer, is armoured like a knight of the middle ages.

The silicate thus exuded is properly called "slag," and thus distinguished from the "cinder" which flows from the furnace. It differs in chemical composition, and is used by the puddler as already stated.

The iron thus beaten into cubical or brick-shaped lumps commonly called puddle bars or blooms, has a rough scaly surface and generally coarse appearance. Its subsequent treatment depends upon the purpose for which it is to be used. Generally speaking, it is reheated in a reheating or mill furnace, and passed between grooved or plain rolls, which either give it at once the shape required, or a convenient approximation to that shape.

At each reheating and rolling a continually diminishing quantity of fusible slag is pressed out, and within certain limits the quality of the iron is correspondingly improved. So important is this improvement, that in many cases the puddled bar is reheated and hammered again with no other object than the improvement of quality. This treatment is expressively described by the workmen as giving it a "wash heat." He evidently sees in this some analogy to the rinsing and wringing work of the laundress.

In the manufacture of the best boiler plates, the full advantages of reheating and rerolling are made available by the ingenious device of "piling." The puddled bar is rolled into a rude oblong plate, usually from ¾ to 1 inch thick. This is cut up into strips, which are piled upon each other crosswise, forming a bundle or fagot, which is placed in the reheating furnace until it reaches a welding heat. The heated pile is then passed through the rolls until it reaches the required thickness. By repeating this process and mixing "scrap," or the cuttings of finished plate with the other pieces of the pile, still further improvement of quality is effected, and "best best" iron is made.

When the plates required are very large, this method of piling enables the workmen to unite in one piece a considerable number of puddled balls. It is thus that armour plates weighing many tons are made. In this case a number of large plates are rolled, and these are piled on each other, primarily for the purpose of increasing the mass, the improvement of quality following as a collateral necessity.

Armour-plate making has shown us that we may easily pass the limits of improvement due to repeated piling and reheating, the plates having in some cases been found to become deteriorated in the latter stages. An interesting series of experiments was made on this subject by Mr. Joshua Jeavons, at the Atlas Works, Sheffield, and the results exhibited by the fractures of the plate after each rolling. The gradual improvement of the silky fibre of the iron up to the fifth, sixth, or seventh heating, the subsequent appearance of dark granules in the midst of the fibres, and their increase with each successive heating afterwards, were very instructive. I found, by chemical analysis, that this kind of deterioration is due to the existence of small quantities of oxides in the midst of the iron, and that these dark granules are the characteristic indications of such internal oxidation or burning,* and have explained the phenomena thus: Ordinary iron contains a small quantity of carbon; when such iron is heated and exposed to moderately active oxidizing agency, the carbon is attacked in preference to the iron; but after the carbon has been thus burnt out, the iron is no longer protected, and itself begins to oxidize. As red-hot iron is curiously permeable by certain gases, this oxidation may take place throughout. The workman appropriately describes iron which is thus deteriorated as "burnt iron." This liability to burning presents one of the great difficulties in the manufacture of armour plates.

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* 'Chemical News,' April, 1871.

Not many years ago 4½ inches was generally believed to be the greatest thickness obtainable in rolled iron plates, any important addition to this being established as impossible. Fortunately, there are some Englishmen endowed with a stubborn disbelief in impossibilities, and one of these, named John Brown, a railway spring and buffer maker, of Sheffield, told the Government authorities that he would make them 7-inch plates. The offer was rejected as visionary and impossible; but as Sir John Brown tells me, in an interesting letter just received, he "volunteered to make plates of 5½ and 7 inches, and should they penetrate them I would not charge for the plates, but should the shot be kept out, I should be paid. *I was paid.* Afterwards we went on increasing up to 14 inches in thickness. The result of the success in the 7-inch gave the authorities full confidence, and at last they were willing to listen to 'an interested contractor.'" Sir John Brown attributes his success to "working to the rule of thumb (knowing no other guide), finding out from day to day, and sometimes *at great cost*, the way to accomplish my desire." I quote this passage as an illustration of what I have long maintained, viz. that the successful artificer is a true and faithful, though unwitting, disciple of Lord Bacon; that the "rule of thumb" intelligently carried out is the same method of observation, experiment, and induction by which the great triumphs of modern science have been achieved, and therefore that science and practice are more closely allied than most people believe.

But to revert to the armour plates. Aided by his able partner, Mr. J. Devonshire Ellis, and by the best workmen that could be obtained from any part of the country, Sir John Brown has fully succeeded in realizing his original vision of a 15-inch armour plate.

The following interesting particulars of the dimensions and weight of some large plates rolled at the Atlas Works, Sheffield, established by Sir John Brown and Mr. J. D. Ellis, have been kindly supplied to me by the latter gentleman:

	LARGEST SIZE AND WEIGHT.									FINISHED SIZE AND WEIGHT.								
1872.	ft.	in.	ft.	in.	in.	t.	c.	q.	lb.	ft.	in.	ft.	in.	in.	t.	c.	q.	lb.
Mar. 1.	25	0×	7	10×	6	20	19	2	16	22	3¾×	7	5 ×	6	17	12	3	17
Mar. 22.	22	0×	8	2×	8	25	13	1	9	19	0 ×	7	10 ×	8	20	14	1	4
1873.																		
May 7.	24	6×	4	4×	1	26	10	3	9	20	11½×	4	0¾×	14	21	5	0	22
July 2.	20	9×	7	2×	11	29	4	0	24	16	3 ×	6	9 ×	11	21	12	0	25
July 5.	18	4×	10	2×	5	16	15	3	12	16	0 ×	9	9 ×	5	13	18	2	9

The difference between "largest size and weight" and "finished size and weight" is due to the fact that each plate has to be squared and cut to specified dimensions. Mr. Ellis regards the last of the above, although the thinnest and lightest, as the best example of manufacturing success, the difficulties of thickness having been so completely overcome that the greater difficulty of increasing *width* is now the main point of attack. A rolled plate 18 feet 4 inches long, 10 *feet* 2 *inches wide* and 5 inches thick, might well be set up on end as a monument of British industry and skill, and would be more worthy of admiration than the biggest of the Egyptian pyramids.

As regards thickness, I may add that all these plates come out of the furnace about 30 inches thick, and thus any of them might have been left at 20 inches, but of smaller area.

As already stated, one of the great practical difficulties in making armour plates arises from the difficulty of reheating these great masses without burning. The furnace in which the "moulds" or large piles are placed is a red-hot chamber big enough to serve as a small parlour. This has to be uniformly heated with the *smoky* flame from a huge fire. The door of the furnace, which is raised by levers like the door of the puddling furnace, must be large enough to admit the great pile of plates, and has to be frequently opened in order that the progress of heating may be watched. As may be supposed, such a door is far from air-tight; the air enters all round, and especially at the bottom. This would be quite sufficient to ruin the plate, but for a remarkably simple and beautiful device of the illiterate but by no means ignorant workman. He places lumps of fresh coal just within the door in such a manner, that they are roasted by the radiations from the flame and red-hot walls of the furnace chamber. What must follow? The coal is distilled, as in a gas or oil retort; its hydrocarbon vapours are given off nearly red hot and greedy for oxygen. As the leakage draught passes over them, these vapours combine with the oxygen, which is not sufficient in quantity for their *complete* combustion. Thus the entering air which would otherwise oxidize the iron is replaced by a mixture of reducing carbonic oxide, nitrogen, and smoky hydrocarbon vapours, which protect instead of destroying the iron. In all their operations, whether with armour plates or the smaller and less difficult reheating furnaces of similar construction for boiler plates, &c., the same device is adopted. The puddler in like manner chokes up his fire-doors with fresh coal when balling, and obtains a similar result. The mill forgeman, like the puddler, has been accused of wasting fuel on account of his smoky fire. Were he to follow the instructions of these very learned and equally superficial critics, the production of useful armour plates or even the best boiler plates would be impossible, for with a clear smokeless fire such as he has so often been urged to use, he would only economize coal by burning iron in its stead, and his plates would be rotten and useless.

STEEL.

By W. Mattieu Williams, F.C.S., F.R.A.S., &c.

Steel, as everybody knows, is a compound or mixture of iron and carbon. Simple as this fact appears, a great deal still remains to be learned or settled concerning the chemistry of steel. The manner in which the carbon is mixed or combined with the iron; whether it exists in the same state of combination in softened and in hardened steel; how it operates in producing the remarkable differences in the properties of iron and steel, are still unknown, and even the proper application of the name "steel" is not settled. Some eminent chemists have maintained that other elements, such as nitrogen, are essential to it.

As already stated, ordinary wrought iron contains a small quantity of carbon, and this may be increased gradually without any clear line of distinction until we get hard iron, semi-steel, mild steel, medium steel, hard steel, very hard steel, brittle steel, and an unweldable compound of iron and carbon, which brings us to the other limit to which the term steel is applied.

What then are the mechanical differences which accompany these successive additions of carbon to the iron?

Iron in its purest attainable state is, as I have already said, infusible in ordinary furnaces, and is softer and tougher than iron containing a barely measureable quantity of carbon. As the proportion of carbon increases, it becomes more fusible, harder, more brittle, and though less tough, is more tenacious.

This apparent contradiction respecting toughness, brittleness, and tenacity demands some further explanation. By tenacity, I mean the force required to tear asunder a piece of given size by a direct pull steadily applied and gradually increased without any blow or vibratory shock. Thus a bar of good wrought iron, one inch square and suspended by one end, will support a gradually increasing weight up to about 20 to 25 tons, at which it is finally torn asunder. The Admiralty standard test for boiler plates is 23 tons to the square inch as the breaking weight. When the iron is otherwise pure, the tenacity thus measured increases within certain limits with the increase of carbon; but the brittleness or liability to break when struck or subjected to a vibratory strain increases also. The breaking strain of fine qualities of steel, containing about 1¼ per cent. of carbon, exceeds 60 tons to the square inch. The increase of hardness conferred by carbon on iron is accompanied with the very important and valuable property of susceptibility to tempering; and when the quantity of carbon is sufficient to render this property quite decided, the compound is properly called steel. If a piece of steel is made red hot and suddenly cooled by immersion in cold water or otherwise, it becomes so hard that it will readily cut another piece of the same steel that has been slowly cooled. Steel containing from $\frac{3}{4}$ to 1 per cent. of carbon, when thus treated becomes so hard and brittle as to be of little practical use, and is then said to be "hardened;" but this hardness is easily modified by "tempering," which renders it somewhat softer and less brittle. The degree of such softening depends upon the temperature to which it is raised in thus reheating.

The workman regulates this temperature by a very simple and elegant device. Having cleaned the surface of the hardened steel, he exposes it to heat in such a manner that he can watch the bright surface. As the temperature rises, this surface becomes coated with a very thin, but gradually thickening, film of oxide, and in accordance with an optical law discovered by Sir Isaac Newton, the colour of such film varies with its thickness. At first it is a pale straw colour, then a deeper yellow, which gradually runs through a brownish yellow to a purple, deepening and changing to violet, then to dark blue, which blue colour fades and dies away into a settled dark grey. If he is tempering a tool used for cutting metal, and therefore obtusely edged, such as a drill, plane iron, turning tool, &c., he "lets it down" to a straw colour. If the tool is for cutting wood and edged more acutely, he goes on to the deep yellow, or what he calls the "nut brown," where yellow is merging into purple. For finer edges, where more elasticity is required, he proceeds to the purple; and for such purposes as watch springs, he raises the heat till the oxide film displays dark blue. This he calls "spring temper." Saws, swords, needles, fish-hooks, &c., are spring tempered. If a saw or sword were left as hard as a file, it would break in the course of ordinary use. The temperature at which the straw colour makes its appearance is about 420° Fahr.; brown 500°; the purple at about 540°; blue about 600°. Tempering is effected by simply placing the tool, &c., upon a hot plate, or in an oven, or by immersing it in a bath of fusible metal.

Steel is somewhat whiter than iron. A drop of dilute nitric acid left for a short time upon a bright surface of steel or cast iron leaves a black stain of carbon, while the spot left upon wrought iron free from carbon is grey.

As already stated, we cannot definitely say where the distinction between iron and steel commences; but, roughly speaking, iron containing any quantity of carbon within $\frac{1}{4}$ per cent. bears the name of wrought iron. From $\frac{1}{4}$ to $\frac{1}{3}$ per cent., we have semi-steel; between this and $\frac{1}{2}$ per cent., mild steel; from $\frac{1}{2}$ to 1 per cent., ordinary steel; and from 1 to $1\frac{3}{4}$ per cent., hard and very hard steel. Above this the compound fuses so readily that it becomes unweldable, i. e. it does not pass into a sufficiently pasty stage on its way to fusion. At about 2 per cent. cast iron begins, but we must avoid the common error of supposing that the difference of carbon constitutes the whole difference between steel and ordinary cast iron.

It is only from iron of the finest quality that steel containing above 1 per cent. of carbon can be made.

The ordinary method of making steel (or of "conversion," as it is termed), which was almost exclusively adopted in this country until lately, was the process of "cementation." Swedish charcoal iron is used for the best qualities, and the purer the iron, the greater the quantity of carbon it will bear. If common iron is used, the steel cannot be forged even with 1 per cent. of carbon, but cracks or crumbles under the hammer when red hot.

The cementing furnace is a cupola-shaped chamber terminating in a chimney, having externally the appearance of a glass-house. These dome-like structures are characteristic features of Sheffield architecture.

At the tower or expanded part of the cupola are two fire-clay troughs or "chests," covered with an arch forming a cavity or chamber above them. These chests are heated by a fire below, and flues arranged around them in such a manner that the temperature shall be as nearly uniform as possible. The iron to be converted is rolled into flat bars, usually about 3 inches wide and ¾ inch thick. The chests vary from 10 to 15 feet in length, and take a charge varying from 12 to 18 tons. Coarsely ground charcoal—that of hard wood preferred—is first spread to a depth of about 2 inches over the bottom of each chest, and upon this charcoal floor a layer of bars is placed, with a space of ½ to ¾ of an inch between each. Then another layer of the charcoal or "cement" is sifted over these to a depth of about an inch, and so on, until the chests are filled to within about 6 inches of the top. The remaining space is then filled with old cement powder, and this is plastered over with damp sand, or the mixture of sand and steel particles obtained from the wearing down of grindstones, or with clay, the object of this upper layer being to form a cake that shall be impervious to air when heated. The bars are placed longitudinally from back to front, so that their ends come to the face of the furnace. The furnace is now closed and no air admitted to the chests, but some trial bars are so arranged with their ends protruding, that they may be withdrawn from the "tasting" or testing holes, and the progress of cementation from time to time examined.

The fire is now lighted and the whole charge gradually raised to a glowing red heat, and kept thus for a week or ten days, according to the required hardness of the steel. When by examination of the testing bars the cementation is shown to have made sufficient progress, there being no core of unconverted soft iron in the middle of the bar, the fire is gradually lowered, finally extinguished, and the furnace cooled. This occupies about another week, the cementation still making a gradually diminishing progress.

The bars at this stage are called "blistered steel," on account of the peculiar condition of their surface, which is covered more or less completely with blisters, arising evidently from the evolution of gas (probably carbonic oxide) a little below their surface. It is by the extent and the appearance of this blistering, and by the "grain" of the fracture, that the workman judges of the amount of carbon which has combined with the iron.

That the carbon should actually penetrate these solid bars of wrought iron and combine with their substance even to the middle, is a very remarkable fact. The experiments of the late Dr. Graham demonstrating the wonderful permeability of iron and other metals to certain gases, assist in explaining the phenomena of cementation, especially as it appears that a certain quantity of hydrocarbon, of cyanogen, or other carbon compounds which become gaseous at a red heat, materially assists the process of cementation. The use of cyanides, such as the common commercial "prussiate of potash," in steel-making is one of those profound secrets, well known to all concerned, which are so grotesquely guarded by certain old workmen in Sheffield.

There is another way of explaining cementation. It is supposed that the surface of the iron bar first obtains, by direct contact with the charcoal, a large dose of carbon; that this superficial film then parts with a portion of its carbon to the film immediately below, or within it, and then regains carbon from the superficial charcoal as at first. Then the second film transfers some of its carbon a stage deeper, and absorbs what it has thus lost from the surface film, and so on, deeper and deeper, the carbon travelling by a sort of convection from particle to particle, or film to film, until the centre is reached.

However this may be, it is practically found, as might be expected, that the outside of the bar contains more carbon, and is consequently harder than the interior; and besides this, there is a notable degree of difference between various parts of the length of the same bar, and between the various bars as compared with each other.

Such being the case, it becomes necessary, in order to obtain anything like the uniformity of composition which is necessary to good steel, to mix these varying portions together. The most obvious, and certainly the most effectual mode of doing this is to cut the bars into small pieces and melt the whole, as is adopted in the manufacture of the best British steel, viz. the "cast steel" or "pot steel" of Sheffield.

The cemented bars are cut up and melted in crucibles or "pots," and then cast into ingots; but this process is costly in consequence of the high temperature required, the fuel consumed, and the rapid destruction of the crucibles. So great is this destruction that, in Sheffield and the neighbourhood, garden walls and other structures are commonly built of old steel pots instead of bricks. "Pot Square" is classic ground in Sheffield history, and is still the centre of its popular political life.

This process of melting is usually applied to the hardest steel, for two reasons. First, that such steel, in order to stand the vibratory shocks to which it is subjected, must be of the best and most uniform quality; and further, because, containing more carbon, it is more fusible than softer qualities.

Although fusion is the most effectual means of securing a homogeneous quality of cemented steel, it is not the only available method. The cheaper and more common mode of treatment of the softer and less fusible steels is to cut the cemented bars into short lengths, pack them together into bundles or "fagots," raise them to a welding heat, and hammer or roll them into bars anew; and this is how "shear steel" is made. When the bars thus rolled are sheared, fagoted, welded, and rolled a second time, we get "double shear," as distinguished from the first, or "single shear" steel. Of course, the double shear is more homogeneous, and therefore better, though at each reheating it loses some of its carbon by the combustion which takes place while the heated steel is brought in contact with the air during working.

"Once upon a time," i. e. before the Commonwealth, when Dud Dudley taught his fellow-countrymen how to use pit coal in the manufacture of iron, it was nearly correct to describe steel as a compound intermediate between wrought iron and cast iron—to define cast iron as a compound of iron and carbon in which the carbon varied from 2 to 5 per cent.; and steel as a compound of iron and carbon, in which the carbon varied from about ½ to about 1¾ per cent. Such a definition, however, when applied to ordinary English cast or pig iron of the present day, is grievously wrong and delusive, but is, nevertheless, quite common even in some of our best chemical and metallurgical treatises. This error has built up a mountain of vexation and misery in the form of a multitude of abortive inventions, or rather repetitions of the same invention.

Accepting the authority of such treatises, a painfully large number of unfortunate men have regarded the above-described methods of making steel as very roundabout, costly, and unscientific. "Why take out all the carbon in the puddling furnace, and then put back one half of it in the cementing furnace?" say they. "Why not stop half-way in course of making the wrought from the cast iron, and thereby obtain the intermediate compound, the steel?" or, "Why not simply mix one part of wrought iron, containing no carbon, with one part of cast iron, containing double the required quantity of carbon, and thus produce the steel?" Infected with such ideas, they have secured costly patents, and made still more costly experiments, which have ended in miserable disappointment, in spite of the soundness of their reasoning upon the given premises.

The fact is, that modern English cast iron is, as already stated, not a mere carburet, but a metallic-looking muddle of many substances, while good steel should be composed of iron and carbon, and the smallest possible quantity of anything else. A compound of iron and carbon, and absolutely nothing else but carbon, would be *perfect* steel, and the business of the steel-maker is to approach as nearly as possible to this; therefore, he first purifies his iron by removing from it, as nearly as possible, all the silicon, sulphur, phosphorus, &c., but in doing this he is compelled to remove the carbon also.

The ancient iron-makers, who used pure ores and wood charcoal, were able to make steel directly, and made it, in fact, more easily than iron. In countries where such ores and charcoal are still used, steel is still made by direct process.

By using "spiegeleisen," or other charcoal iron, or an exceptionally pure brand of English pig iron; by working this with an abundant fluid cinder, which covers and protects from oxidation the granules as they come to nature, and by skilful damper manipulation and smoky firing, a steel may be produced in the puddling furnace varying in quality with that of the raw material used. The puddled steel commonly made in this country is, however, unfit for tool-making, or any decent cutlery, but may be used for rails, ploughshares, &c.

I have said that the inventors who have tried to make steel directly from ordinary English cast iron have all failed; but, like the alchemists who tried without success to transmute vulgar metals into gold, some of them have in the course of their efforts discovered something else of considerable value. This was notably the case with Mr. Bessemer, who obviously started with the plausible theory above described, and sought to partially decarbonize pig iron by blowing air through it, stopping at the point where the remaining portion of carbon should produce steel. He did decarbonize, and did make the theoretical intermediate product, but when made from ordinary English pig, it was worthless for the purposes of steel. By indomitable perseverance, however, he succeeded in achieving other results of such importance that the Bessemer process demands special description, even in so brief a treatise as this.

In the first place, a very careful selection of pig iron is made, that produced from hæmatite being generally used. It must contain but a very small proportion of phosphorus, not more than one-tenth per cent. The proportion of sulphur should also be small, but it may be quite double that of phosphorus. Manganese is advantageous. From 1½ to 3 per cent. of silicon is desirable, and the pig should be decidedly rich in carbon. Grey iron, containing 3 or 4 per cent. of graphitic carbon, is preferred.

The following is the average result of my own analyses of thirteen samples of pig iron made and used expressly for Bessemer purposes. One was a Swedish pig, the other twelve English hæmatite pigs.

Combined Carbon	0·47
Graphite	2·72
Silicon..	2·84
Phosphorus	0·08
Sulphur	0·14
Manganese	0·90
Iron by difference	92·85
	100·00

The manufacture of "Bessemer pigs," or iron specially adapted to this process, has now become an important business.

These pigs are melted in a cupola or other suitable furnace, from which the melted metal is poured by means of a trough into the "converter," which is a pear-shaped vessel; a vertical section of which is shown in Fig. 1. It is lined with fire-clay, or ganister, and has a flat circular bottom, which is made removable, as it requires frequent renewal.

This bottom is fitted with fire-clay cylinders, shown at *c d*, *c d*, *c d*, *c d*, each cylinder being perforated from end to end with holes of ½ to ¾ of an inch in diameter. The bottom is thus riddled with sixty, seventy, or a hundred or more of such holes, according to the size of the converter. These holes communicate with a powerful blowing machine through the air chamber *c*, *c*, *c*, *c*.

The converter is mounted on an axis at *i*, upon which it may be turned over by suitable machinery. When about to be charged (the lining having been made red hot by burning coal inside) it is turned over until the line *e f* is horizontal, the melted metal is poured in at the spout *a*, and lies in the belly of the converter below the line *e f*. When thus charged the blast is turned on, after which the converter is turned to the upright position, and the melted metal stands on the perforated bottom, as shown in the figure.

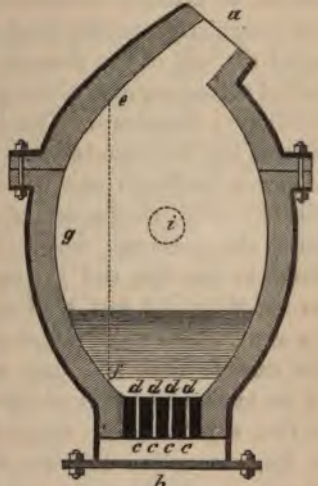

Fig. 1.

It is thus resting directly on the air which fills the perforation, and would of course fall through if in the quiescent state shown in the diagram, but this is prevented by the force of the blast, the pressure of which exceeds the weight of the metal resting upon it, which is thus driven from the holes faster than gravitation can pull it through them. If the blast were checked for a moment, the melted metal would rain through these openings, solidify below, and do serious mischief.

The "blow" has now commenced; the hundred streams of air are tearing through the pool of melted iron, and a huge flame roars furiously from the mouth of the converter. With this flame magnificent cascades of brilliant coruscating sparks are belched forth irregularly, and the dazzling spray, as it dashes against the wall of the flame-shaft, rebounds with redoubled splendour, each glowing globule bursting into scintillating fragments. The blast roars on monotonously, but the flame becomes brighter and brighter, and grows in length and breadth as it increases in brilliancy until, at the end of about ten minutes, it attains its maximum, when its splendour becomes painful to the eye, and yet so fascinating, that few who see it for the first time can turn their dazzled eyes away. The spark eruptions still burst upwards from time to time, still dash against the brickwork and the ground, and still reverberate in fiery splinters, but their appearance has changed; they are no longer red hot, nor yellow hot, nor white hot, but have a curious and characteristic purple luminosity, which is possibly due to the dazzling impression of the flame, for sunlight itself has a sickened partial-eclipse effect, and at night all ordinary gaslights appear red and smoky to eyes thus dazzled. After five or ten minutes of this maximum splendour the flame is seen to contract, and presently the ponderous vessel turns over deliberately, the flame disappears, and the uninitiated spectator is startled by a new display, for as the converter rolls over, the blast tears across the sloping surface of cinder which rests above the melted metal, and dashes it out in a huge cascade of sparks, which the rotation of the converter spreads out into a fan-shaped volley, extending from end to end of the building, and descending in a broad sheet of fiery hail.

The trough from another cupola furnace is now swung round to the mouth of the converter, and a second charge is poured in. This is the spiegeleisen, the composition and functions of which will be presently explained. As it mixes with the first portion of the charge, a furious ebullition takes place, and a great mass of pale blue carbonic oxide flame pours forth with a quiet leisurely waving, that contrasts curiously with the previous roar of the white flame.

The Bessemer metal or steel is now made, and is next cast into ingots of various sizes, according to the purpose for which it is required. This is effected by first pouring it from the converter into the "ladle," which is a large pot with refractory lining and a plug at the bottom. It is large enough to take the whole charge, usually five or six tons, but in some cases considerably greater. The ladle is at one end of an oblong platform, which is swung horizontally upon an axis, and thus it describes a wide circle. The ingot moulds are arranged in a semicircular row immediately below the orbit of the ladle, and thus as it is swung round the plug passes successively over the mouths of each mould. By this means the moulds are filled in succession by opening and closing the plug as the ladle is placed successively above them.

The object of thus tapping from the bottom is to pour out the steel free from the lighter and floating cinder, which rapidly cools and solidifies into a crust on the upper part of the ladle. A simple but rather important improvement has lately been made upon the method of pouring. Instead of swinging the ladle round over each mould in succession as above described, the whole charge is now poured into one mould and this communicates from below with the *bottom* of each of the others. Thus the metal is poured from below upwards in all but the first, and is thereby rendered more compact, more free from air holes or entangled cinder.

The following are the changes which take place during the blow:* First, the silicon and the manganese are oxidized, and simultaneously the graphitic carbon is converted into combined carbon. Fusible cinder is formed by the combination of the silicic acid and oxide of manganese. As the quantity of uncombined silicon diminishes, the oxidation of the carbon commences, and goes on increasing, reaching its maximum when the flame is the brightest. It thus appears that the silicon and possibly the manganese, by their greater affinity for oxygen, protect the carbon from oxidation while they exist in considerable quantity. In like manner the carbon, until it is reduced to about a quarter per cent., protects the iron from rapid oxidation. A certain amount of oxidation of iron does,

* Those who desire to further examine the evidence of these changes, will find them stated in a paper which I contributed to 'Nature,' March 9, 1871, p. 374.

however, take place, even in the earliest stages of the process, as shown by the cinder and the sparks; but, unfortunately, the sulphur and phosphorus remain unmoved. All this oxidation or combustion is attended with a great evolution of heat, the amount of which may be best conceived by calculating the actual quantity of carbon, silicon, and manganese that are oxidized during the short period of the blow—about twenty minutes.

With a charge of six tons, and the above-stated proportion of carbon, silicon, and manganese, the absolute weight of the very effective fuel they form amounts to above 8 cwt. This is a very large quantity to be burned in so small a space during only twenty minutes, and when we remember that it is burning in the midst of the melted metal, it is not at all surprising that the steel should be raised to a very high temperature and effectively fused. The Bessemer process affords the most effective means yet devised for fusing large quantities of steel, or of iron containing but little carbon.

But what is spiegeleisen? and why is it used in the manner described? It is a variety of imported cast or crude iron, made with charcoal from very rich ores containing much manganese.* It is the whitest of white iron, crystalline in structure, and derives its name of "spiegel," or "mirror iron," from the brilliancy of its cleavage planes. The following is the average result of my own analyses of four ordinary working samples:

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* The demand for spiegeleisen has now overrun the original sources of supply, and home-made substitutes have been recently produced.

Combined Carbon	4·20
Graphite	0·42
Silicon	0·93
Phosphorus	0·06
Sulphur	0·17
Manganese	6·63
Iron by difference	87·59
	100·00

Mr. Bessemer's first attempts to produce merchantable steel, by simply stopping the blow at the moment when the carbon of the pig iron was reduced to the quantity required for steel, were unsuccessful. He could not determine when this occurred, and there was something wrong in the steel, even when the carbon happened to be in proper proportion.

The use of the spiegeleisen overcomes the first of these difficulties completely, and the second partially. Although we cannot say when the amount of carbon has reached one per cent. or one-half per cent., or any other steel-making quantity, we can tell by the change of the flame when the carbon is so nearly exhausted that it ceases to protect the iron from combustion, for as this point is approached the flame contracts and alters its character. This is the signal for turning over the converter and stopping the blow; the melted iron being now combined with about one or two tenths per cent. of carbon, and some entangled particles of iron oxide being diffused throughout it. At this stage it is utterly unfit for any of the ordinary uses of either iron or steel. It is "rotten," and can neither be rolled nor hammered.

Let us suppose that this has to be converted into a mild steel, containing half per cent. of carbon and that the sample of spiegeleisen to be used has five per cent. of carbon, we can easily calculate the amount to be added. If there are 4½ tons of such melted iron, half a ton of spiegeleisen will supply the whole with the required half per cent. of carbon. In this manner the quantity of carbon may be regulated with a very near approach to accuracy. In well-conducted Bessemer works a laboratory sample is taken of the finished steel of every blow, and the percentage of combined carbon in this is analytically determined by a very short and easy process, devised by Professor Eggertz. This determination serves as a continual check upon the proportion of spiegeleisen to be used, and indicates the purposes to which the steel is applicable.

The violent agitation and the great volume of blue flame which follow the addition of the spiegeleisen are doubtless due to the reduction of the free oxide of iron by the carbon of the spiegeleisen, and the consequent evolution and combustion of carbonic oxide gas. Thus the spiegeleisen not only supplies the required proportion of carbon, but also reduces the chief cause of rottenness, the burnt iron.

The ingot moulds into which the steel has been poured in the manner already described are made of cast iron, nearly cylindrical, larger at bottom than top, and open at both ends. They stand upon a fire-clay tile, and are well packed around the bottom, to prevent leakage there. They have lugs or handles at the upper part, by which they are lifted clear off the glowing ingot, as soon as it is solidified, by means of a hydraulic crane. These ingots are then picked up by tongs attached to the same machinery, and carted off to the hammer shops, where they are beaten out into convenient forms for rolling, &c.

The cost of Bessemer steel is about one-fourth of that of the cast steel above described. Like this, it has, when carefully made, the important quality of uniform composition and hardness, but it is usually unfit for the manufacture of edge-tools and good cutlery. Ordinary Bessemer steel will not bear more than about three-fourths per cent. of carbon, and some samples not so much. With a larger quantity it cracks or crumbles under the hammer. I have given much attention to this subject, and find that the more phosphorus the pig of which it is made contains, the less carbon can the steel take; and I have seen a few exceptional blows made by the late Mr. G. Brown, from exceptionally fine "Cleator" pig and superior spiegel, that have borne above one per cent. of carbon without failure. In these cases the result was a high quality of tool or cutlery steel.

The retention of the sulphur and phosphorus of the pig is the great practical drawback to the Bessemer process. In spite of this, however, it has effected something like a revolution in our iron industry; not by superseding good steel for cutlery purposes, but by enabling us to use a coarse or semi-steel for purposes to which iron was formerly applied, and a much cheaper steel for rude and heavy steel implements. Bessemer steel rails are more than ten times as durable as those of common iron. Tires for railway-carriage wheels are made of the same material, and should be adjusted so as to contain about one-tenth per cent. more carbon, and be consequently a little harder than the rails upon which they run.

As the tenacity of Bessemer steel is much greater than that of iron, it is of great value for structural purposes, such as steel bridges, roofs, &c. Boilers made of this material will bear the same pressure of steam as iron of much greater thickness; but in all these applications great care is necessary in watching and checking the proportion of carbon, for if a plate of a boiler or any important element of a steel structure were made too hard, it would be dangerously brittle, and thus endanger the whole. This possibility has seriously limited the use of Bessemer steel for such purposes, especially as the large manufacturers are so much occupied with the more wholesale and ruder work of rails and tires, that they do not care to bestow the necessary scientific attention demanded for the production of high quality Bessemer steel. I have long maintained that there should be a division of labour in this respect, and that an important and lucrative business may be done by any manufacturer who, with a small or moderate plant, would devote himself exclusively to the careful production of the highest quality of Bessemer steel, by freely availing himself of all the advantages which chemical science places at his disposal for this purpose.

As already stated, several inventors have patented the idea of making steel by simply fusing cast and wrought iron together, in the proportions required to give the mixture the necessary quantity of carbon. From what has already been explained, it will be understood that all such attempts must fail if common English cast iron is used, as its composition is so different from the theoretical cast iron.

By the "Siemens-Martin" process steel has been successfully made by fusing cast and wrought iron together, but not by *simply* mixing them.

The source of heat in this process is the admirable and effective regenerative furnace of Dr. Siemens, wherein not only is a higher temperature obtained than by any other coal-burning furnace, but it is obtained most economically, and is capable of such modification that an oxidizing neutral or reducing flame may be used at pleasure. The importance of this in the working of iron and steel cannot be overrated.

In such a furnace pigs of the best quality, similar to those used for the Bessemer process, are melted. Into this bath of fused pig iron, white-hot pieces of bar iron, scrap iron, or the scrap ends of Bessemer rails, &c., are gradually thrown, and when the charge is complete and all melted, the mixture is subjected to the action of an oxidizing frame. Ladle samples are taken out from time to time, and tested by sudden quenching in cold water and breaking. When the toughness of the test samples shows that the decarburization is nearly complete, spiegeleisen is added, as in the Bessemer process, for the same purpose and with like results, and ingots similar to those of Bessemer steel are cast.

The chief value of this process depends upon its availability as a means of working up Bessemer and other scrap, such as the cuttings of boiler plates, ends of rails, shavings from planing machines, &c.

Dr. Siemens has recently made some very important developments of this process. On the bed of an intensely heated regenerative furnace he introduces about 6 tons of hæmatite pig, which is soon melted there. Rich iron ore, free from sulphur and phosphorus, such as hæmatite or other oxide, mixed with lime and other fluxing materials, is added to this. An ebullition, similar to the "boiling" in the puddling furnace, takes place, owing to the combination of the oxygen of the ore with the silicon and carbon of the pig metal. Two objects are thus simultaneously achieved, viz. the partial purification of the pig, and the reduction of the ore into metallic iron. The action is watched and tested as above described in the Siemens-Martin process, and when about 30 cwt. of ore has been added, and the carbon of the whole is reduced to about one-tenth per cent., eight or ten per cent. of spiegeleisen is added and well stirred in. The steel now made is tapped into a ladle, and cast into ingots, hammered, &c., as in the Bessemer process.

The most ambitious and important of recent attempts to improve the manufacture of iron is also an invention, or series of inventions, of Dr. Siemens, by means of which he proposes not merely to supersede the old converting furnace and the puddling process, but the blast furnace also, and to render pig iron a thing of the past.

In this, as in both of the processes just described, the source of heat is the regenerative gas furnace, to which is added, for the present purpose, a cylindrical iron melting pot or crucible, about 9 feet long and 7 feet 6 inches in diameter, with a lining of about 7 inches in thickness, formed of bricks composed of a mixture of "*Bauxite*" with clay, or with silicate of soda and plumbago. Bauxite is the name of a mineral found at Baux, in France, and is composed chiefly of alumina. The invention of the Bauxite bricks overcame one of the chief difficulties of the process, for so great is the heat demanded, and capable of being supplied by the regenerative furnace, that bricks made from the best fire-clay hitherto used were so rapidly burned away, that a lining of these 6 inches thick was reduced after a fortnight's working to less than half an inch, while a Bauxite lining was only 5 inches thick and perfectly compact.

This cylindrical furnace or melting pot is mounted on friction rollers and connected with machinery, by which it can be made to rotate slowly or quickly, as desired. It further differs from an ordinary melting pot by being heated from the *inside* instead of the outside. This is effected by passing through it, while rotating, the gases of the regenerative furnace, so that the whole of the inside lining is thus intensely heated.

The ore to be smelted is broken up into small *fragments not* exceeding the size of peas or beans, while to it is added a properly adjusted proportion of lime or other fluxing material. The charge, containing about one ton of ore, is put into the furnace fully heated and revolving slowly. It is thus brought into contact with successive portions of the heated lining, besides being heated directly by the gaseous fuel in contact with it. In about forty minutes, when this charge of ore and flux has attained a bright red heat, about 5 or 6 cwt. of small coal of uniform size and not larger than nuts, are added to it, and the velocity of rotation increased. The coal combines with some of the oxygen of the ore, and reduces it to a lower and fusible oxide, which is further reduced to metallic iron as it comes in contact with each piece of carbon. At the same time the silica of the ore combines with the flux and forms a liquid cinder.

While this reducing action is going on, carbonic oxide is formed by the combination of the oxygen of the ore and the carbon of the coal. This carbonic oxide, being itself an inflammable gas, requires but a supply of air to render it an effective fuel. Accordingly, during this reaction, only heated air is admitted, instead of the gas flame of the regenerator. A great economy is thus effected as compared with the blast furnace, where the heat obtainable by the combustion of carbonic oxide is for the most part lost.

When the reduction is completed the fluid cinder is tapped off, and a quick speed given to the rotator, in order to ball up the granules of iron. The balls thus formed are taken out and treated in the same manner as the balls for the puddling furnace.

A mild steel, similar to puddled steel, is formed by stopping the action before the reduction is complete, or a cast steel is obtained by adding spiegeleisen to the iron, and rapidly raising the heat by an abundant supply of gases from the regenerator. The granular iron thus melts with the spiegeleisen, and the resulting steel is tapped into moulds and treated as in the Bessemer process.

Instead of pouring the spiegeleisen into the rotator containing the reduced iron, it is obvious that the balls of iron may be conveyed to another rotator containing the fused spiegeleisen. Dr. Siemens gives a preference to this, especially as several charges of iron may thus be combined, and charges of 5 or 6 tons of fluid steel be made.

He asserts that by this method a "ton of iron can practically be produced with a consumption of 14 cwt. of coal, and a ton of cast steel with 12 cwt. of coal," i.e. about one-fourth of the quantity that is used in the ordinary course of manufacture.

This announcement was made at a recent meeting of the Chemical Society, at which Mr. Lowthian Bell and several others well acquainted with the practical details of iron-making were present. Mr. Bell expressed a difficulty in believing its possibility, though, like all the rest present, his scepticism was powerfully tempered by respect for the scientific reliability of Dr. Siemens.

Although iron has been made in England from the time of the Roman occupation of the island, it is only during the life of many living ironmasters that the manufacture has become one of the most important elements of British industry. The iron used by our ancestors was chiefly imported from Russia and Sweden, and at the beginning of the present century our home production had not overtaken the home demand.

In 1788	we produced	61,300	tons	of pig iron.
1796	”	108,799	„	”
1806	”	250,000	„	”
1820	”	380,000	„	”
1827	”	654,500	„	”
1845	”	1,200,000	„	”
1851	”	2,500,000	„	”
1865	”	4,819,000	„	”
1870	”	5,963,513	„	”
1871	”	6,627,179	„	”
1872	”	6,741,929	„	”
1873	”	6,566,451	„	”
1874	”	5,991,408	„	”

The quantity of coal used in producing all the pig iron made

In 1872	was	17,211,729	tons.
1873	„	16,718,532	„
1874	„	15,292,201	„

The returns for 1875 are not yet completed. It is probable that they will indicate a continuance of the decline which has been going on during the last few years.

I suspect that we have touched the summit of our productive power, so far as *pig or crude iron* is concerned. We are not likely ever again to reach the approximate 6¾ millions of tons of 1872. Our richest and most accessible coal seams are already exhausted, or nearly approaching exhaustion, and we can only supply our present consumption by working deeper and less productive or more costly deposits. As the market price of any commodity is regulated by the value of the most costly portion of it, we must look forward to continuous increase in the price of coal, and the consequent starvation of the industries most dependent on cheap coal. It is commonly supposed, and positively stated, that the manufacturing supremacy of Great Britain is due to her coal-fields and other mineral treasures. While fully admitting that for the manufacture of pig iron an abundant supply of cheap fuel is indispensable, I cannot conclude this sketch of the most voracious of our coal-consuming industries without a protest against the fallacy of attributing our industrial success to coal or ironstone, or any other mere mineralogical or geographical accident.

It is not British minerals, but British industrial energy which has given us our industrial supremacy. It is not true that we are so exceptionally rich in coal. Many other nations possess vastly greater stores than ours;* but while theirs has lain buried under their feet, ours have been brought to the surface and wondrously used; to such an extent indeed, that we are actually approaching the limits of our supply before other and older peoples have tapped theirs.

I know of no single fact of human history more expressive of the dominant energy of one particular race than the comparative condition of our coal-fields, and would suggest to those who fear that British prosperity will collapse as they become exhausted, the conclusion, that the same energies which have thus seized upon and utilized the rudest source of power to supply the coarser wants of ourselves and the rest of mankind, will, if properly directed, similarly turn to account the more refined and recondite energies of nature which science is revealing, and which will supply in like manner the higher wants of more advanced civilization. To succeed in this we must prepare at once, by affording to all classes the largest attainable amount of knowledge of the raw materials and powers of nature; of human means of turning these to profitable account; of the social organization in the midst of which we live, and by which we are able to co-operate industrially with each other and all the peoples of the earth; and, above all, of the individual moral qualities, habits, and attainments that are necessary for each man's industrial success.

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* The reader may obtain further information on this subject from an article on "The Limits of our Coal Supply," which I contributed to the 'Quarterly Journal of Science' of July, 1873.

Give us this education, and we need not fear the gradual exhaustion of our coal-fields. Quoting a recent conversational remark of a great economist, I may say with him that "it is not quite desirable that England should always be the coal-cellar of the world." There is plenty of better work demanded, and every reason why Englishmen should do it. A ton of iron made into rails is worth about 10*l.*; the same weight of chronometer springs is worth many thousands of pounds. In such a case, for every pound of value due to the coal and ironstone, a thousand is added by human skill and labour. With imported pig or bar iron we may still be great iron-workers, by leaving the ruder operations to others, and doing the higher work at home.

The gradually increasing scarcity of our coal may thus, if we rightly use its warning, urge us to higher efforts, and a greater degree of prosperity than the mere abundance of raw minerals could possibly afford.

COPPER.

By J. Arthur Phillips, Mem. Inst. C.E., F.G.S., F.C.S., &c.

Of the metals employed by the ancients for the manufacture of tools, weapons, domestic vessels, and coins, copper appears to have been the most important. This is amply proved by the writings of the earlier historians, whilst the vast number of implements and other relics which have come down to us from prehistoric times, induce us to believe that there was a period when copper with its alloys was almost the only metal in general use; though it is quite possible that iron may also have been employed, since, owing to its perishable nature, objects made of it would be more speedily destroyed by oxidation.

Considering, however, the amount of metallurgical skill required to make definite alloys of copper and tin, or copper and zinc, it appears probable that the first copper was not so alloyed, but merely detached from pieces of native metal, and subsequently fashioned, by hammering and grinding, into the required forms.

Copper obtains its name from the island of Cyprus, and is distinguished by Pliny as *Æs Cyprium*, or Cyprian copper; but by degrees the substantive was dropped, and the metal known as cyprium or cuprium, from which our word copper is derived. According to Pliny, two sorts of copper were exported from Cyprus: one called *Coronarium*, which, when reduced to thin leaves and tinted with the gall of an ox, had a golden colour, and was used in the manufacture of tinsel ornaments; of the other, termed *regulaire*, no description is given, excepting that, like the last, it would bear hammering, and could consequently be made thereby to take any desired form.

It is probable that much of the copper employed in prehistoric times was obtained from scattered pieces of the native metal, such as are frequently found at the present day in the district of Lake Superior; though the cutting up and removal of a large mass of native copper would require a greater amount of skill and better tools than the smelting of some of the simpler ores.

Ancient copper mines, discovered on the shores of Lake Superior, show that the search for this metal was prosecuted with considerable skill and perseverance. Throughout the whole extent of that region from Keweenaw Point to a considerable distance beyond the Ontanagon, and even on Isle Royal, numerous excavations for the purpose of procuring copper have been found, which must evidently have been made at a very remote period.

Some of these workings are on a very extensive scale; in one instance attaining a depth of 50 feet in the solid rock. The principal tools discovered in them were the so-called stone hammers, or small rounded boulders having a groove cut around them for the purpose of attaching a handle. These were accumulated in great quantities in some of the workings, together with a few copper tools; and mingled with them were considerable quantities of charcoal, indicating that the method of attacking the rock by fire was resorted to, as is still the case in some parts of Europe. Unfortunately, there are no remains of either dwellings or of burial places, which might serve as a clue to the race by which the work was executed.

The Indians at present inhabiting the district have no traditions relative to copper mining in the region, and have no idea how or by whom the work was accomplished.

All the older writers appear to have used the terms bronze, brass, and in a few instances copper also, as synonymous, much as we now speak of brass guns and brass coinage, but which should more correctly be called *bronze*, a term now only applied to alloys of copper with tin, *brass* being an alloy of the former metal with zinc. The brass mentioned in ancient writings consisted in most cases of an alloy of copper and tin, although, where we read of brass being "molten out of the stone," or "out of whose hills thou mayest dig brass," we may conclude that an ore of copper is alluded to. Nevertheless, there can be no doubt that the manufacture of true brass was well understood by the Romans.

Much discussion has arisen with regard to the composition of the alloy known as orichalcum, which was greatly valued by the ancients on account of its fine colour, in some cases difficult to distinguish from that of gold. It seems probable that many of the yellow alloys of copper were included under this title; but Festus, in an abridgment of a work of the time of Augustus, shows that orichalcum was zinc-brass, since he states that cadmia was an earth which, when thrown upon strongly heated copper, produced orichalcum.*

This is intelligible, when we consider that if an ore of zinc, such as the carbonate, be thrown upon copper at a temperature below its fusing point, in the presence of carbon, zinc is reduced to the metallic state and instantly absorbed by the copper, the product being brass.

A process of this kind, known as the calamine brass process, was described in the early part of the eleventh century by Regerus the monk; and this is practically the same as that which, under the same name, was in use in this country until within about fifty years of the present time. This method consisted in heating a mixture of calamine and granulated copper with coke dust in crucibles, to a temperature somewhat short of the melting point of copper; the reduced zinc is absorbed, and the alloy is obtained in a state of fusion, its melting point being considerably lower than that of unalloyed copper. Aristotle also informs us that the Mossynæci anciently prepared a brass of pale colour by mixing copper, not with tin, but with a certain earth, doubtless identical with the cadmia of Pliny, who, however, appears to have also applied this term to an ore of copper.

The following analyses of coins made some years since by the author, show the proportions of the constituents employed in the manufacture of brass at times both preceding and closely following the Christian era:

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* "Cadmia terra quæ in æs conjicitur, ut fiat orichalcum."

	Date.	Copper.	Zinc.	Tin.	Lead.	Iron.
Large brass of the Cassia family	B.C. 20	82·26	17·31	—	—	·35
Ditto of Nero	A.D. 60	81·07	17·81	1·05	—	—
Ditto „ Titus	„ 79	83·04	15·84	—	—	·50
Ditto „ Hadrian ..	„ 120	85·67	10·85	1·14	1·73	·74
Ditto „ Faustina ..	„ 165	79·14	6·27	4·97	9·18	·23

It will be seen that copper and zinc were the essential constituents of the alloys examined, but that lead was sometimes present in considerable quantities, together with tin and iron; the presence of the latter being probably due to the impurity of the materials employed.

Although zinc occurs in such considerable quantities in these alloys, it was not known in the metallic state until about the thirteenth century, when it was described by Albert of Bollstadt.

Many analyses of ancient articles of bronze have been made, and our knowledge of this alloy is considerably greater than of the alloys of zinc.

The proportion of the constituent metals was varied according to the purpose to which the alloy was to be applied, as will be seen from the following analyses; the hardness being modified according to the proportion of tin present. The hardest alloys containing the largest amount of tin were used for mirrors, whilst those of medium hardness were used for the manufacture of sword-blades and other cutting instruments:

	Copper.	Tin.	Lead.	Iron.	Cobalt.	Analyst.
1. Chisel, from ancient Egyptian quarry..	94·00	5·90	—	·10	—	Wilkinson
2. Bowl, from Nimroud	89·57	10·43	—	—	—	Dr. Percy
3. Bronze overlaying iron.. ..	88·37	11·33	—	—	—	"
4. Sword - blade, Chertsey, Thames	89·69	9·58	—	·33	—	J. A. Phillips
5. Axe-head..	88·05	11·12	·78	—	—	Prof. Wilson
6. Celt	81·19	18·31	·78	—	—	"
7. Roman As, B.C. 500	69·69	7·16	21·82	·47	·57	J. A. Phillips
8. Julius Cæsar	79·13	8·00	12·81	—	—	"

The third specimen in the above Table is especially worthy of attention. It was analyzed by Dr. Percy, who describes it as a small casting in the shape of the foreleg of a bull, forming the foot of a stand, consisting of a ring of iron supported upon three bronze feet. A longitudinal section disclosed a central core of iron, around which the bronze had been cast. It is difficult to judge whether this was done for the purpose of economizing bronze, in which case iron must have been far more plentiful than has been generally supposed, or to give strength to the tripod and enable it to sustain a considerable weight. The latter seems the more probable conjecture, the stand having perhaps been employed to support a heavy cauldron.

Some writers, in order to account for the immense masses of hard stone wrought by the Egyptians, have supposed that they possessed some means of hardening bronze to a degree equal, if not superior, to that of our steel; this, however, requires confirmation, since no remains of bronze of this hard variety have ever been discovered. Indeed, Wilkinson found a chisel at

Thebes, of which, though he believes that it was used for cutting granite, he says, "Its point is instantly turned by striking it against the very rock which it was used to cut; and yet, when found, the summit was turned over by the blows which it had received from the mallet, whilst the point was intact as if it had recently left the hands of the smith who made it." This shows that copper tools, if used at all for the cutting of such material as granite or porphyry, must have required very frequent sharpening.

Our knowledge of early mines worked for copper is exceedingly scanty, although from the magnitude of such works as the Colossus at Rhodes, we may infer that they must have been of considerable extent and inportance in order to have yielded such large quantities of the metal.

As far as this country is concerned, copper was raised in Cumberland in the thirteenth century, rich veins of ore being worked at Keswick in the year 1250. A charter granted to this town by Edward IV., A.D. 1470, proves it to have been, at that period, the seat of extensive copper works. Ecton Hill, in Staffordshire, also produced copper ore long before the era of copper mining in Cornwall, where systematic explorations for the ores of this metal were probably commenced about the year 1700. The Parys mine, in Anglesea, is said to have been opened by the Romans, and became exceedingly productive in 1773. During the twelve succeeding years it yielded such large quantities, as to materially reduce the price of copper throughout Europe.

That nothing was known of the large deposits of copper ores in the United Kingdom in the reigns of Henry VIII. and Edward VI., is shown by the Acts of Parliament passed during those periods for preventing the exportation of brass and copper, "lest there should not be metal enough left in the kingdom fit for making guns and other engines of war, and for household utensils." Even as late as 1708 it was evidently supposed that ores of zinc were far more abundant in this country than those of copper, from the following clause in a petition from the brass manufacturers to the House of Commons: "England, by reason of the inexhaustible plenty of calamine, might become the staple of brass manufacture for itself and foreign parts; and the continuing of brass works in England would occasion plenty of rough copper to be brought in."

Until within a comparatively recent date England stood pre-eminent for the production of copper; during one hundred and twenty-six years, ending 1855, Devon and Cornwall alone producing 7,184,305 tons, which realized 50,964,388*l.* sterling. The quantity of copper ores raised in various parts of this country, in 1874, was as follows:

SUMMARY OF THE PRODUCTION OF COPPER IN THE UNITED KINGDOM FOR 1874.*

Countries, &c.	No. of Mines.	Ore.	Value of Ore.			Copper.			Value of Copper. (*Computed.*)		
		Tons.	£	s.	d.	Tons.	cwt.	qr.	£	s.	d.
ENGLAND.											
Cornwall ..	78	40,455	201,367	18	8	2,770	14	0	249,263	0	0
Devonshire ..	14	12,826	52,746	0	0	916	2	0	82,440	10	0
Cumberland ..	3	813	3,663	7	10	56	18	1	5,050	0	0
Lancashire ..	2	935	4,128	5	10	75	0	0	6,750	0	0
Cheshire	1	8,184	6,475	0	0	89	9	2	7,900	0	0
Yorkshire ..	1	128¼	2,608	11	0	35	0	0	3,150	0	0
Staffordshire ..	1	¼	2	0	4	0	0	2	2	18	0
WALES.											
Cardiganshire .	2	93	338	5	6	5	16	2	522	15	0
Carnarvonshire	2	138	632	6	0	9	12	2	865	0	0
Anglesea.. ..	3	4,925	8,250	0	0	135	1	0	12,150	0	0
Merionethshire	1	5	45	0	0	0	15	0	67	0	0
Montgomeryshire	2	84	580	0	0	6	0	0	570	0	0
ISLE OF MAN .	1	61	289	6	4	5	8	0	470	0	0
IRELAND.											
Sold at Swansea Ticketings .	5	8,776	50,218	10	0	716	4	0	64,440	0	0
Wicklow . ..	3	997	4,120	13	0	85	10	0	7,650	0	0
Regulus, *Precipitate, &c., sold at Ticketings* .	—	100	950	0	0	74	0	2	6,600	0	0
Total of the United Kingdom	119	78,521	336,414	18	6	4,981	11	3	447,891	3	0

TOTAL QUANTITIES OF BRITISH AND FOREIGN COPPER ORES AND REGULUS, &C., SMELTED, AND COPPER PRODUCED IN ENGLAND AND WALES IN 1874.

Where produced and sold.	Ore and Regulus.	Copper.
	Tons.	Tons.
Total Copper Ores of the United Kingdom	78,521	4,981
Colonial and Foreign Ores, Regulus, and Precipitate, sold at Swansea Ticketings	22,217	4,847
Colonial and Foreign Ores not sold at Ticketings (*Estimated*)	25,800	5,297
Colonial and Foreign Regulus and Precipitate not sold at Ticketings (*Estimated*)	27,500	8,750
Pyrites (*Burnt Ore*) producing Copper (*Estimated*)	450,000	9,000
Total	604,038	32,875

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* From 'Mineral Statistics, &c., for 1874.' By Robert Hunt, F.R.S.

Recently great quantities of copper ore have been obtained from Australia, where large deposits of the carbonates and oxides, &c., are found. The island of Cuba has also produced it in abundance; but the supply from this locality, as well as from the once famous mines of Burra Burra, in South Australia, has latterly greatly fallen off. Few countries, if any, yield a larger annual amount than Chili, though we are unfortunately not in possession of accurate statistics of the production of South American mines. In North America, the district of Lake Superior is exceedingly rich in native copper, which, in some cases, has been found in masses of over 100 tons in weight, too large to remove, and requiring to be cut into manageable blocks by means of hammer and chisel. Within the last twenty years a considerable quantity of cupreous iron pyrites has been imported into this country from Spain and Portugal. The sulphur present in this mineral is employed for the manufacture of sulphuric acid, while from the residue, copper is extracted by the wet process, hereafter described. During the year 1874 the imports of this ore amounted to nearly 500,000 tons, most of which was raised at the mines of San Domingos, in Portugal, and at Tharsis, in Spain. In both these mines old workings have been discovered, with tools, sandals, coins, and other remains, proving that they were worked by the Romans.

In addition to the copper sent into this country in cupreous iron pyrites, a considerable quantity of ore, too poor to pay for exportation, is treated at the mines by a humid process, the resulting copper precipitate being sent to England to be smelted.

The copper obtained from the celebrated Ecton Mine, in Staffordshire, already referred to, was smelted at the village of Ellaston, near Ashbourne, probably in the early part of the seventeenth century, since Plot, writing in 1686, informs us that the mills at Ellaston were dismantled when he visited them.

Copper smelting appears to have been carried on to a limited extent during the last century in Yorkshire, works being mentioned as existing at Middleton Tyas about 1750. In Lancashire smelting was commenced about 1717, and works erected near Warrington, which were abandoned towards the close of the century. Others were then established at St. Helens, and lasted until about 1813. No copper smelting appears to have been carried on in Lancashire during the next twenty years, when works, which are still in operation, were established at Sutton and Ravenhead, near St. Helens.

No place in Great Britain now produces annually a larger quantity of merchantable copper than Swansea. Copper works do not, however, appear to have existed there prior to the year 1720, although smelting was carried on at Neath at least a century before.

Several times during the last century unsuccessful attempts were made to smelt copper in Cornwall, but at the present time there are no copper works in that county. From the writings of Pryce and others, it appears that the Cornish miners attributed their failure to conspiracy on the part of the Swansea smelters; but it was more probably due to the fact, that the ores could be more profitably treated in Wales, where fuel was much less expensive.

At the present time the English industry of copper smelting is chiefly carried on in South Wales and in Lancashire.

ORES OF COPPER.

Comparatively few of the copper minerals are of much importance to the metallurgist, by far the largest proportion of this metal annually produced by the world being obtained from copper pyrites.

NATIVE COPPER (*Gediegen Kupfer; Cuivre natif*) is cubical, occurs crystallized in octahedrons, sometimes modified, lamellar, filiform, or arborescent, and has a specific gravity = 8·83. No known locality produces such large quantities as the region of Lake Superior, where it occurs in veins intersecting trap rocks, frequently associated with metallic silver. In small quantities native copper is of frequent occurrence, but except in the region above mentioned, it is not of much importance as an ore. It is generally remarkable for great toughness.

CUPRITE (*Red oxide of copper; Roth Kupfererz; Cuivre oxydulé*)—composition Cu_2O—is cubical, generally in cubes and octahedrons, of a ruby-red colour, with a specific gravity = 6, and contains, when pure, 88·80 per cent. of copper.

MELACONITE (*Black oxide of copper; Kupferschwärz; Cuivre oxydé noir*)—composition CuO—is cubical;

rarely found crystallized, but more commonly earthy; is massive, or pulverulent, affording, when pure, 79·82 per cent. of copper.

MALACHITE (*Green carbonate of copper; Berggrün; Cuivre carbonaté vert*) crystallizes in the oblique system, the crystals being often very complicated; occurs more frequently massive or incrusting, the surface being botryoidal or stalactitic. Specific gravity $=3 \cdot 7$ to $4 \cdot 1$. Its composition is $CuCO_3$, CuH_2O_2, yielding, when pure, 57·33 per cent. of copper. This mineral frequently occurs near the surface, in veins producing sulphides and other ores of copper, and has probably been derived therefrom by atmospheric agencies.

AZURITE (*Blue carbonate of copper; Lasurit; Cuivre carbonaté bleu*)—composition $2CuCO_3$, CuH_2O_2—crystallizes according to the oblique system, and also occurs massive. Its specific gravity is 3·5 to 3·81; contains, when pure, 55·16 per cent. of metallic copper. It occurs largely in South Australia, and was formerly found at Chessy, near Lyons; and is hence sometimes called Chessylite.

CHALCOPYRITE (*Copper pyrites; Kupferkies; Cuivre pyriteux*—composition Cu_2S, Fe_2S_3)—is prismatic, often in hemihedral forms, though more commonly massive, with specific gravity $=4 \cdot 2$; containing, when pure, 34·81 per cent. of copper. This, which is the most important ore, rarely contains, as sent to market, more than 12 per cent. of that metal, and frequently less.

BORNITE (*Purple copper ore; Buntkupfererz; Cuivre panaché*) crystallizes in the cubical system, and has a specific gravity = 4·4 to 5·5. Its composition varies, sometimes $3Cu_2S, Fe_2S_3$; copper from 50 to 70 per cent.

CHALCOCITE (*Grey sulphide of copper; Kupferglanz; Cuivre vitreux*) is prismatic, and of specific gravity 5·7; its composition is Cu_2S, yielding, when pure, 79·70 per cent. of copper.

TETRAHEDRITE (*Fahlerz*). The composition of this ore is extremely complex and variable, consisting of sulphide of copper with sulphides of antimony, arsenic, bismuth, silver, mercury, iron and zinc.

In addition to the foregoing the following, chiefly interesting to mineralogists, may be mentioned:

CHRYSOCOLLA, a hydrated silicate of copper.

ATACAMITE, a hydrated oxychloride of copper.

ASSAYING.

In order to ascertain the commercial value of an ore it is necessary to determine by a trial on a small scale, called an assay, the percentage of metal which it contains, as well as the presence or absence of any deleterious substances which might either render the extraction of the valuable metal difficult, or so deteriorate its quality as to affect its market price.

CORNISH METHOD.—By this method the metal is first concentrated in the form of a regulus or sulphide; formerly even the copper present in oxides and carbonates was obtained in this form, by addition of sulphur. It is now more usual with oxidized ores to omit processes 1 and 2 of the following Table, which represents the series of operations commonly adopted.

1. Fusion for Regulus.	3. Fusion for Coarse Copper.
2. Roasting the Regulus.	4. Refining.

5. Cleaning the Slags.

1. *Fusion for Regulus.*—The ore, if containing considerably more sulphur than is necessary for the formation of a sulphide with all the copper present, is either previously roasted, or nitre is added to the fusion in order to expel the excess. By this means the regulus obtained is not so largely contaminated with iron, a portion of which being deprived of its sulphur becomes oxidized, and passes into the slag as silicate or boro-silicate. In cases where the sulphur present in the ore is insufficient to form a good regulus, powdered sulphur is added with the other fluxes, consisting of borax, glass, lime, fluor-spar, &c. The proportion of these added must be such, that the button of regulus may be readily detached from the slag without breaking.

The quantity of ore taken for assay varies from 200 to 400 grains, according to its richness.

2. *Roasting the Regulus.*—The regulus obtained in the foregoing operation is, after being detached from the slag, ground very fine in an iron mortar, and placed in a small crucible over a gentle fire; sulphurous acid is evolved, and the ground regulus is kept continually stirred with an iron rod to prevent clotting. Towards the end of the operation, which must be continued so long as any trace of sulphurous acid is evolved,

the temperature is considerably increased. The roasting usually occupies from twenty minutes to half an hour.

3. *Fusion for Coarse Copper.*—The chief reagent employed to reduce to the metallic state the copper contained in the roasted regulus, is a mixture of tartar and nitre, the tartar being in excess of what is necessary to form carbonate of potash with the nitre. Other substances are, however, usually added, some assayers employing borax, others glass, carbonate of soda, or common salt. The product of this operation consists of a button of coarse copper, containing iron and other impurities. It is generally convex on the upper surface, and when nicked with a chisel breaks "short" on being struck; the fracture is fine grained, dull and greyish or orange in colour.

4. *Refining.*—This process is conducted in the same crucible which has been used for operation 3. The flux employed is made by deflagrating a mixture of three volumes of tartar, two of nitre, and a small quantity of common salt.

The crucible is placed in the fire just beneath the junction of the two tiles, forming the cover of the furnace. When it has become bright red-hot, the button of coarse copper is dropped in, the furnace is nearly closed, and the progress of the assay watched through the crevice between the covering tiles. The metal is speedily fused, and at first appears dull from a covering of metallic oxides, but afterwards exhibits what is technically known as the "eye," that is, clear bright edges with a dark variegated centre. On the appearance of this, a small quantity of refining flux is projected into the crucible from a copper scoop, and after the lapse of about two minutes the contents of the crucible are poured into a mould. The button is covered with a grey or flesh-coloured slag, from which it readily separates.

The copper button, if "fine," that is, free from impurities, is more or less flat and coated with an orange-red film, the copper being tough, breaking with difficulty, and exhibiting a silky fracture. More commonly it contains a considerable quantity of oxide, and has an indentation on its upper surface; its fracture is then granular and it has a purplish colour. If the button presents the appearance of coarse copper, it is not sufficiently refined, and must a second time be subjected to this process. When over-refined, the surface of the button is coated with a crimson film, and a considerable quantity of copper passes into the slag, to which it imparts a red colour; in this state it is said to be burnt. The process of refining is simply one of oxidation; those metals more oxidizable than copper, such as lead, iron, and zinc, being acted upon, separate from it in the form of oxides.

5. *Cleaning the Slags.*—The slags obtained in process 3, and which have been preserved, together with those from the last process, are roughly ground and mixed with tartar or charcoal. This mixture is fused and poured into a mould. When cold the slag is crushed, and any small shots of copper, known as "prills," picked out, and, if necessary, refined. Their weight is added to that of the principal button.

This method of assaying affords considerably lower results than any of the humid processes; the deficiency varying greatly with the nature and richness of the ore, and being proportionately much greater on poor ones.

Wet Assay.—The humid methods are more correct and expeditious than fire assay, and, moreover, far less skill is required in conducting them; but notwithstanding this, ores are invariably bought and sold by dry assay. The only advantage which has been put forward for this method is, that it gives the smelters an idea of the quantity of the copper which will be lost in smelting, and of the quality of the copper which will be produced; the process consisting essentially of the same operations, on a small scale, as are carried on in copper smelting.

For the humid assay of copper many processes have been devised, but space will only permit me to describe that in which cyanide of potassium is the chief reagent and which is now generally employed.

The standard solution is prepared by dissolving about 125 grammes of what is known as photographic cyanide, in 2¼ to 2½ litres of distilled water. The solution is then standardized in the following manner: Two pieces of pure electrotype copper, weighing from ·5 to ·75 gramme each, are placed in separate flasks, and dissolved in dilute nitric acid; the solution is boiled to expel nitrous fumes, and diluted to about a quarter of a litre. Ammonia in excess is then added to each solution, when a fine blue colour is produced. A burette capable of holding from 50 to 60 cubic centimetres is to be filled with the cyanide solution to the uppermost division.

As soon as the copper solution is quite cold, cyanide is gradually run into it until the blue colour is discharged, when the number of cubic centimetre divisions of cyanide which have been used is read off. The solution of the second piece of copper is proceeded with in precisely the same manner: from the data thus obtained the amount of copper equal to 50 cubic centimetres of the cyanide solution is calculated, the mean of the two results being taken.

This standard solution is somewhat liable to decomposition and requires to be restandardized every few days; it should be kept in green or blue bottles, made of glass free from lead.

A weighed quantity of the ore to be assayed is now placed in a beaker or flask, moistened with sulphuric acid, and strong nitric acid added; the whole is then digested at a gentle heat, more nitric acid being added from time to time, until red fumes of nitrous acid cease to be evolved; and in some cases hydrochloric acid is also added.

The solution is considerably diluted and excess of ammonia added; the ferric hydrate which is usually precipitated may be disregarded. When the solution has become cold, the cyanide solution is cautiously added, the copper solution being stirred from time to time, until the colour is discharged, with the exception of a faint lilac tint; the number of divisions required to produce this effect is noted, and from the standard the percentage of copper may be readily calculated.

The presence of silver, nickel, cobalt, or zinc, renders this process untrustworthy, unless some special means for their separation be adopted.

Silver may be got rid of by the addition of a little hydrochloric acid to the solution and its subsequent filtration, when the chloride of silver remains on the filter, whilst all the copper passes through it in solution.

Zinc, Nickel, or Cobalt, when present, may be separated by precipitating the copper in acid solution, either by immersing a piece of clean iron into it, or by passing sulphuretted hydrogen through it. In the first case the copper is thrown down in the metallic state, and in the second as sulphide; in either case, the zinc, nickel, or cobalt remains in solution, and the precipitate is collected and washed, and afterwards dissolved in nitric acid, and estimated by cyanide of potassium in the usual way.

In assaying ores consisting chiefly of sulphides, it will be preferable to eliminate some of the sulphur by calcination. For this purpose a weighed quantity is placed in a porcelain dish and heated over a gas-burner or in a muffle furnace, the ore being stirred with an iron wire during the roasting; the residues are treated with acids, and the assay conducted as before.

This process for the estimation of copper is capable of affording exceedingly good results in the hands of an experienced assayer, more especially if the ore operated on be not very rich. This method is best suited for the assay of ores or slags containing from one to seven per cent. of copper, although richer ores may be treated by diluting the cupreous solution and operating on a measured quantity of it.

COPPER SMELTING.

The English Method, by means of which a very large proportion of the copper annually produced is extracted from its ores, consists usually of six distinct operations, which are conducted in reverberatory furnaces of two classes, termed respectively calcining and melting furnaces; the fuel employed being a mixture of binding and free-burning coal burnt on a clinker bed. To the mixing of the ores which are to be smelted together great attention must be paid; the mixture should be neither too poor nor too rich in copper, but should contain from 9 to 13 per cent. of that metal.

After calcination, the mixture should be capable of being fused without the aid of fluxes, and should yield a clean and readily fusible slag; the regulus or matt obtained in this first fusion ought to contain about 30 per cent. of copper.

1. *Calcination.*—Having obtained a suitable mixture of ores, it is subjected to calcination in a reverberatory furnace, of the form represented. (Figs. 1 and 2.)

This furnace is built of common brick, but is provided with an internal lining of fire-brick, indicated by the close shading. At one end is the fireplace (*a*), the bars of which are supported upon two bearers; whilst a third bearer serves as a support for the bar used in breaking up the clinker bed. The fire-bridge is traversed by an air channel (*d*), communicating with the interior of the furnace by the orifices (*c*).

The charge is introduced through three openings *e* in the arch, which are closed by cast-iron plates during working; and these are fitted with hoppers of sheet iron (*f*). On each side of the bed, which is flat, are three doors (*i*), and close to these are the openings (*g*), through which the calcined ore is raked into arched vaults (*h*) beneath the furnace, which are made to communicate with the chimney, in order that any sulphurous acid evolved after drawing may be carried off. The orifices (*g*) are closed during the working of

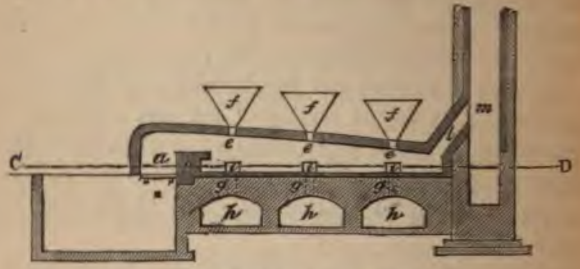

Fig. 1.—Vertical Section on the line A B.

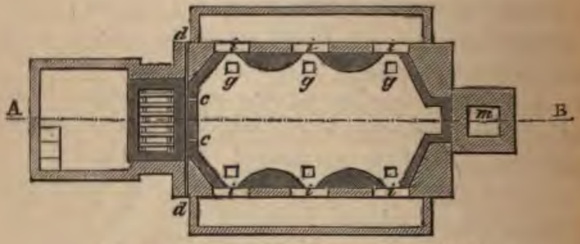

Fig. 2.—Horizontal Section on the line C D.

ORE CALCINER.

the furnace by fire-tiles placed over them. Between the doors on either side brick projections are built, to prevent any accumulation of the ore, where it could not be reached by the rake. At the end of the furnace remote from the fireplace a flue (*l*) communicates with the stack (*m*). The whole structure requires to be strongly braced together by upright and transverse iron bars.

The charge for a calciner of this description is about 3 tons, which is spread evenly over the bed. The temperature is then gradually raised, and the charge stirred at intervals, in order to bring every part of it into contact with the air which enters through the doors and also through the channel in the fire-bridge. During calcination, the temperature should never be allowed to become sufficiently high to cause a clotting of the ore. The time occupied by this operation varies, according to the nature of the ore, from twelve to twenty-four hours. When completed, the ore is drawn through the holes (*g*) into the vaults below, and should then have a prevailing brownish-black colour.

At the present time, owing to increase in the price of labour, fuel, and other materials, it is necessary to conduct the operations of copper smelting with great economy, and it is therefore usual to roast the mixture of ores in a muffle furnace, the fuel employed being gas generated in Siemens's producers. The furnaces are supplied with Siemens's regenerative apparatus; and in order to ensure that the charge shall be thoroughly and equally heated, a fire-bridge is placed at each end, and an arrangement made by which the draught is reversible, and the gas can be introduced at either end of the furnace.

By the use of a muffle furnace, contact between the products of combustion and the sulphurous acid evolved from the ore is avoided, and the latter is converted into sulphuric acid, and condensed in leaden chambers in the usual manner.

The old form of reverberatory roasting furnace allows the sulphurous acid and smoke to escape into the atmosphere together, thus causing a great loss of sulphur, and at the same time an intolerable nuisance to the neighbourhood in which the copper works are situated.

2. *Fusion of Calcined Ores for Coarse Metal.*—The calcined ore from process 1 is fused in a melting furnace, with slag obtained from the ore furnace in operation 4, and known as *metal slag;* the products being regulus and slag. The melting furnace employed is represented in Figs. 3 and 4. The bed is built upon an arched chamber (*a*) extending from the fireplace (*b*) to the opposite end of the furnace. On the top of this arch a flat platform of brickwork is built, and on this is constructed the bed itself, which consists of sand hollowed out so as to form a shallow oval cavity, which inclines from all sides towards the taphole (*c*). The bed is prepared by distributing over the platform, before referred to, a layer of sand about 1 foot thick, which is then strongly heated, and a layer of metal slag spread over it. This, on melting, forms a cement which solidifies the sand.

A second layer of a few inches of sand is then spread er the surface, and another stratum of slag melted on it; these alternations of slag and sand being repeated, until a thickness of about 20 inches has been attained.

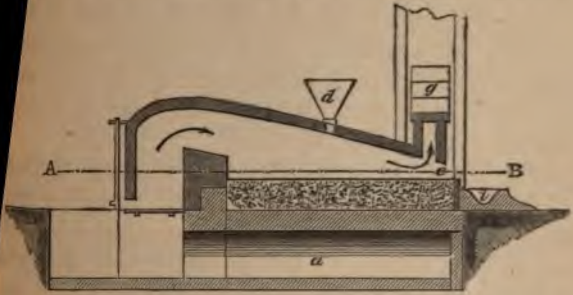

Fig. 3.—Vertical Section on the line C D.

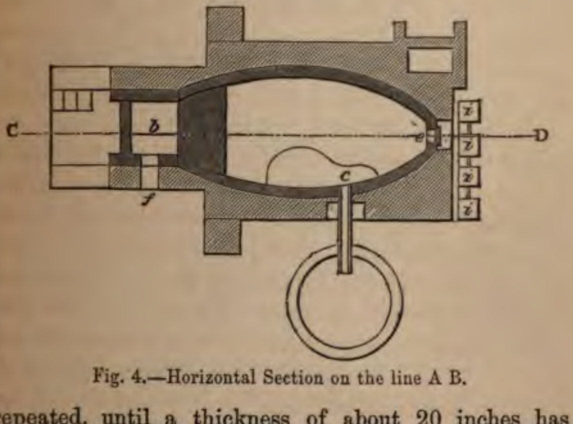

Fig. 4.—Horizontal Section on the line A B.

The charge of ore is introduced through a hole in the roof, furnished with a hopper (*d*), closed by a sliding plate. The opening (*e*) at the end of the furnace serves both for the introduction of the slag, which forms part of the charge, and for the removal of that which remains at the conclusion of the operation. Fuel is introduced through the orifice (*f*) into the fireplace (*b*). This opening has no door, but is kept closed by a heap of small coal. Two melting furnaces are usually connected with one stack by means of flues, as shown at *g*. In some cases, however, each furnace has an independent stack.

The interior of the furnace is composed of fire-brick, indicated in the figures by dark shading, whilst the outer portions are built of common brick; the whole structure, including the stack, being firmly braced together by iron bars.

The operation of melting is conducted as follows: The tap-hole is stopped with a mixture of clay and sand, and the calcined ore introduced through the hopper (*d*), and spread evenly over the bed; metal slag is then thrown in through the opening (*e*), when the orifices are closed and the fire is made up. In about five hours the charge should be melted: it is then well rabbled, and the slag drawn off through the end door into a series of rectangular moulds (*i*). The consistency of this slag is a matter of great importance, since, if too liquid, it may not be easy to distinguish between the slag and the regulus beneath; and if too thick, some regulus may be drawn off with it.

The slag when cold is taken from the moulds, and any regulus which it may contain and which will have subsided to the bottom is detached and mixed with that in the furnace; the slag itself being thrown away.

The regulus is allowed to remain until the bed is full, and to effect this the furnace has to be several times recharged; it is then allowed to run through the tap-hole (*c*) into a circular brickwork pit filled with water. The "granulated coarse metal" which results, is caught in a perforated iron box fitting the inside of the pit, which may be raised by means of a crane, in order to allow the water to drain off. It has, however, of late been the custom in some copper works to omit this granulation, and, instead, to run the coarse metal in moulds; the cakes so obtained, after grinding, being placed in a furnace similar to that shown in Figs. 3 and 4, and roasted.

3. *Calcination of the Coarse Metal.*—If the coarse metal has been subjected to granulation, it is next calcined during twenty-four hours in a flat-bedded reverberatory furnace, similar to Figs. 1 and 2. When granulation is omitted, the cakes obtained by casting the coarse metal in sand moulds are sometimes roasted during the same period in a melting furnace; the roasting consisting of keeping the metal liquid, and allowing at the same time free access of air. Whichever process is employed, the object is the same, viz. the elimination of a portion of the sulphur, and the oxidation and removal as slag of certain metallic impurities present in the coarse metal.

4. *Melting the Calcined Coarse Metal.*—The calcined or roasted coarse metal is next fused in a melting furnace, with the addition of copper-producing

materials rich in the oxides of that metal, such as natural carbonates or oxides of copper, together with "roaster" and "refinery slags," produced in the two following operations. The products of the melting should be a regulus termed *white* or *fine metal*, and a slag known as "metal slag," which is drawn through the door in the end of the furnace on to a sand bed, and employed in operation 2.

When the proportion of oxidized ores added is too small, a coarse regulus containing iron results, known as *blue metal;* if, on the other hand, too large a quantity of oxidized ores be added, *pimple metal* is obtained, owing to too much sulphur having been eliminated, and a portion of the copper reduced to the metallic state in consequence.

White metal is an almost pure sulphide of copper, (Cu_2S), and contains about 75 per cent. of that metal: it is, as a rule, free from the presence of metallic copper, whilst blue metal, which contains a large proportion of sulphur, usually contains numerous cavities, into which fine filaments of copper project like teeth. Upon analysis it is found that blue metal possesses an amount of sulphur insufficient to form Cu_2S and FeS with all the iron and copper present, and it therefore seems probable that molten blue metal has the power of dissolving metallic copper, which copper is liberated upon the cooling of the mass. If the copper had existed in the metallic state during fusion, it would doubtless be found in shot-like globules at the bottom of the mass, and not disseminated through it in the form of filamentary and angular fragments.

5. *Roasting the White or Fine Metal.*—In this operation it is sought to expel as completely as possible all the sulphur contained in the regulus, and to obtain metallic copper tolerably free from impurities. To effect this, the pigs of white metal are separately introduced through a side door in the roaster, and laid in their proper position on its bed by means of an iron paddle. The introduction of the charge, which consists of from 3 to 3½ tons, greatly cools the furnace, and as soon as it has all been introduced, the door is luted on, and the temperature kept up so that the whole may become fused in from six to seven hours, while free access of air is permitted during the operation, through orifices on either side of the furnace near the fire-bridge; the molten regulus is kept in a state of constant ebullition by the escape of sulphurous acid gas generated in the interior of the mass, where there is no direct contact with air.

This phenomenon, which at first appears difficult to explain, may be accounted for by the formation of oxide of copper on the surface, which being carried by eddies to various depths, reacts upon the undecomposed regulus in the manner expressed by the following equation:

$$Cu_2S+2CuO=4Cu+SO_2.$$

This mutual reaction is of great importance in all roasting operations. Towards the completion of the process the temperature is allowed to fall sufficiently low to cause the charge of regulus to solidify, and the surface being thrown up into craters by the escape of gas affords a large area for oxidation. On remelting the charge, the oxide which has been formed on the surface comes in contact with the undecomposed sulphide, and the reaction mentioned above again takes place. The products are *blister copper*, containing 95 per cent. of copper, but contaminated by the presence of small quantities of iron, sulphur, tin, antimony, &c., and "roaster slag," which is twice removed from the surface of the regulus; the first time immediately after fusion, and the second previously to tapping the blister copper, which is run into moulds of sand.

6. *Refining and Poling.*—The furnace employed in this operation, which has for its object the conversion of blister copper into a marketable product, is similar to a melting furnace, excepting that it has no tap-hole, the bottom inclines gradually from all parts towards the end door, near which is the deepest part of the furnace, and on one side there is a large door. The charge consists of from 8 to 10 tons of blister copper, which is introduced through the side door and melted down; any slag which may be formed is now skimmed off, orifices for the admission of air are opened, and the copper subjected to its oxidizing action during about fifteen hours. At the end of this time the metal should be in the state of "dry copper," or copper which has taken up the maximum amount of suboxide (Cu_2O), which it is capable of absorbing.

The state of the molten metal is ascertained by the refiner, who from time to time takes out a small ladle full, and, from the colour and fracture which it exhibits, is enabled to judge of the degree of oxidation. The final operation of poling is then proceeded with. The molten dry copper is covered with a layer of anthracite, in order to protect the surface from further oxidation. After a short time the end of a green birch or oak pole is plunged beneath the surface of the metal, and kept immersed by placing a prop beneath the end which projects from the furnace. Large quantities of vapour, together with various gases produced by the decomposition of wood, are evolved, and the copper is splashed about in all directions.

A small sample is occasionally taken out by the refiner, who, from practice, is enabled to judge from its appearance whether it has arrived at the "tough pitch," that is, has become soft, malleable, and of good colour. When this is found to be the case, the pole is withdrawn, and the coal pushed back by means of a rake introduced through the end door, through which the copper is then laded into moulds by means of wrought-iron ladles; each ladle has a capacity of about 30 lb., and is coated with clay by dipping it into a mixture of fire-clay and water, in order to prevent the iron being attacked by the molten copper.

It is difficult to state exactly how much time the operation of poling requires, since this depends both on the state of the furnace and on the quality of the copper. As a general rule, however, it is about an hour and a half, the lading of the copper taking about the same time. In some cases the metal absorbs oxygen during the lading and becomes too dry, and in this case it must be subjected to a further poling. On the other hand, should the metal be overpoled, the coal is withdrawn from its surface and air admitted. The presence of a small proportion of suboxide is necessary to the formation of tough cake copper, owing probably to the fact that as long as any copper remains as oxide, the more oxidizable metals which constitute its most common impurities are not reduced to the metallic state, and, therefore, cannot alloy with the copper.

The state of copper, with regard to the quantity of suboxide contained, may be seen to a considerable extent by the appearance of the ingot. If too large an amount of suboxide be present, a longitudinal furrow will be observed on the surface of the ingot, and the metal, which will be of a purple colour, will be brittle, breaking with an uneven fracture. An ingot of copper at the *tough pitch* exhibits a comparatively level surface, is broken with difficulty, and exhibits a silky fracture with a salmon-red colour.

In the overpoled state copper presents a longitudinal ridge, in place of the furrow observed in underpoled copper; the metal is brittle, and breaks with an uneven and orange-coloured fracture.

When intended for rolling, it is usual immediately before lading to add to the charge of refined copper a variable quantity of lead, amounting to a few pounds to the ton; this renders the ingots sound and free from air spaces.

The following Tables show the average composition of some of the more important products obtained in copper smelting.

CUPREOUS PRODUCTS.

	Coarse Metal.	Blue Metal.	White Metal.	Blister Copper.	Bottoms of Best selected Process.
	Le Play.	Le Play.	Le Play.	Le Play.	Napier.
Copper	33·70	56·70	77·40	98·40	78·00
Iron	33·60	16·30	·70	·70	2·50
Nickel, Cobalt, and Manganese	1·00	1·60	traces	·30	
Tin	·70	1·20	..	..	13·80
Antimony			·10	·40	
Arsenic	·30	..		..	·40
Sulphur	29·20	23·00	21·00	·20	3·90
Slag	1·10	·50	·30		
Lead	..	..	..	..	·80
Total	99·60	99·30	99·50	100·00	99·40

SLAGS (Analyses by Le Play).

		Ore Furnace Slag.	Metal Slag.	Roaster Slag.	Refinery Slag.
Silica (combined)		30·00	33·80	47·53	47·40
,, (uncombined)		30·00			
Alumina		2·90	1·50	3·00	2·00
Protoxide of Iron		28·50	56·00	28·00	3·10
Dioxide of Copper (Cu_2O) ..		..	·90	16·90	36·20
Metallic Copper		..	..	2·00	9·00
Various Oxides (Mn, Ni, Co)		1·40	2·10	·90	·40
Lime		2·00	1·40	traces	1·00
Magnesia		·60	·30		·20
Regulus Mechanically Mixed	Copper ..	·50	2·90		
	Iron	·90	·30		
	Sulphur ..	·60	·80		
Calcium Fluoride		2·10			
Protoxide of Tin		..	..	..	·20
Total		99·50	100·00	98·33	99·50

When copper of a particularly pure description is required, as for brass making, the following modification of the processes described is resorted to; the product being known as "best selected copper." White or fine metal is subjected to a partial roasting, by which about a quarter of the copper present is reduced to the metallic state; this, passing through the mass of regulus, subsides to the bottom, carrying with it nearly all the metallic impurities originally present in the white metal, but more especially tin. The contents of the furnace are run into moulds, and when cool the regulus is detached from the impure copper known as "bottoms," which is sent to market as "tile copper." In many cases the white metal is subjected to a second roasting, by which a further amount of copper is reduced, the remaining regulus being roasted for "blister copper," which is refined by itself.

In addition to tile copper, in the form of thin rectangular slabs, this metal is prepared for the market by being cast into ingots of two sizes, varying from 7 to 9 lb. and from 14 to 18 lb. in weight, the best selected being always made into ingots of the latter size. Smaller ones are occasionally made for export; and copper was likewise formerly prepared as "bean," and "feathered shot," by pouring it in a molten state into hot and cold water respectively, in which form it was employed in the old process of calamine brass making; it is, however, now no longer in request.

WET PROCESS FOR THE EXTRACTION OF COPPER.

This process is only suitable for the treatment of ores of low produce, but has within the last few years increased in importance to an enormous extent, owing to the great demand for cupreous iron pyrites in the manufacture of sulphuric acid. The ore—as imported into this country chiefly from Spain and Portugal, but also from Norway—consists essentially of bisulphide of iron, containing a small percentage of copper. In the manufacture of sulphuric acid, the sulphur is expelled, in the form of sulphurous acid, by exposing the ore in kilns to the action of heat and atmospheric oxygen; by this means, where the operation has been properly conducted, the sulphur may be removed with the exception of about 3 or 4 per cent. The resulting residue or "burnt ore" has the following average composition:

Sulphur	3·66	
Arsenic	0·25	
Iron	58·25	= 83·00 Fe_2O_3
Copper	4·14	
Zinc	0·37	
Cobalt	traces	
Lead	1·24	
Lime	0·25	
Insoluble matter	1·06	
Moisture	3·85	
Oxygen and loss	26·93	
	100·00	

Silver 18 dwt. per ton.

Soluble in water = sulphate of copper 4·12 per cent. = 1·65 Cu.

This is ground and passed through a sieve of sixteen holes to the square inch, and subjected to calcination with a sufficient quantity of salt to transform all the copper present into cupric chloride. The calcination is performed either in common reverberatory furnaces or in muffle furnaces. In the first case, the flame and products of combustion pass over the bed and come into direct contact with the ore; in the second, the charge is placed in a brickwork chamber, between which and the outer walls the flame and smoke circulate without coming into contact with the ore. In a third form of furnace, the flame passes through flues beneath the bed, and then passes back over it as in the ordinary reverberatory furnace.

The roasted burnt ore is then treated with hot water, by which the copper is almost entirely washed out, and afterwards precipitated by wrought-iron scrap; the residue from which the copper has been extracted is employed as an ore of iron. Almost all the silver present in the burnt ore passes into the copper liquors, and unless some special method is employed to intercept it before the liquors reach the precipitating vats, it will be precipitated with the copper. In Claudet's process the silver is intercepted by the addition of a sufficient amount of iodide of potassium or of some other soluble iodide to the copper liquors. In this way the silver is precipitated as iodide, which is allowed to collect in the bottom of the tank in which the operation is conducted. The desilverized copper solution is afterwards run into the precipitators, and treated in the usual way.

Mr. T. Gibb has patented a process for extracting the silver, by precipitating 5 per cent. of the copper present in the liquors by sulphuretted hydrogen, when a large proportion of the silver will be found to have been precipitated with it.

Calcining Furnace.—This consists of a flat-bedded furnace, either heated by gas from a Siemens's producer or by an independent fire. The form now most commonly employed is represented in Figs. 5, 6, and 7.

The fuel used is gaseous, consisting chiefly of carbonic oxide, obtained by the partial combustion of coal in a gas producer, mixed with various hydrocarbons. From the producers the gas passes into a flue (*a*) running beneath a series of furnaces which it thus supplies with fuel; from this flue it passes into a distributing box (*b*), from which it is admitted through five holes (*c*), into flues running beneath the bed. On reaching the opposite end of the furnace, the burning gas rises through the flues (*d*), and passes over the firebridge (*e*). After traversing the furnace bed upon the upper side, the products of combustion, &c., pass into a short flue (*f*) connected with a downcast chimney (*g*) in communication with the flue (*h*), which is common to several furnaces, and conveys the gases to a tall chimney, passing on their way through a tower filled with loose brickwork, down which a stream of water continually flows. This water, meeting with such condensable gases as sulphuric and hydrochloric acids, dissolves and carries them with it into a wooden tank at the base of the tower. The slightly acid liquid thus obtained is used in washing copper from the calcined burnt ore, and is of material assistance to the process.

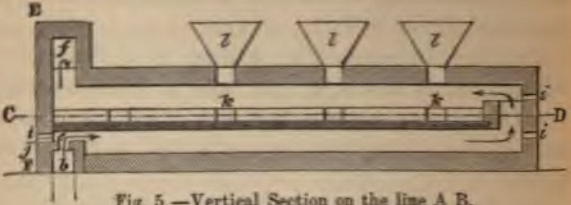

Fig. 5.—Vertical Section on the line A B.

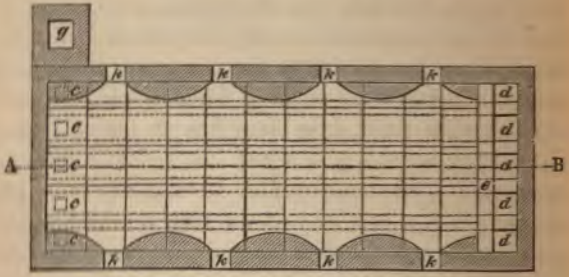

Fig. 6.—Horizontal Section on the line C D.

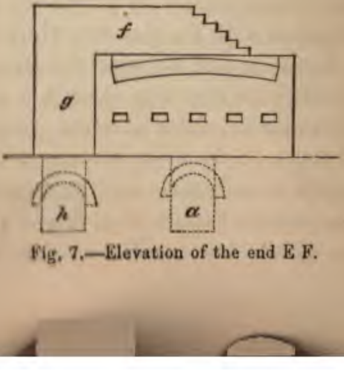

Fig. 7.—Elevation of the end E F.

The air requisite for the proper burning of the gas in the calciner is supplied through air holes (*i*), closable by sliding iron plates, by a careful adjustment of which the temperature at either end of the furnace may be regulated. Dampers (*j*) serve to cut off the gas entirely by closing the openings (*c*).

The furnace bed is composed of rebated fire-tiles, 4 inches in thickness, the edges of which on two sides rest upon the divisions of the flues, shown by dotted lines in Fig. 6.

There are four doors (*k*) on either side of the furnace; those on one side being employed for the introduction of the tools used in working the charges, and those on the opposite side for the withdrawal of the charge of calcined ore.

The charge consists of from 3 to 4 tons of a mixture of ground burnt ore with salt, together with a small quantity of unburnt pyrites in cases where the sulphur is not sufficiently in excess of the copper. It appears to be requisite that there should be in the mixture about a half per cent. more sulphur than copper. The quantity of these is estimated from day to day, and the amount of unburnt pyrites necessary to produce this excess is added.

The mixture is introduced into the furnaces through apertures in the roof, which are supplied with hoppers (*l*), closable when necessary, by cast-iron plates. The charge is spread evenly over the bed of the furnace, and is stirred at intervals with rakes and paddles, in order continually to expose fresh surfaces to the oxidizing action of the air. This roasting is carried on for a period of from six to eight hours. Towards the close of the operation an average sample is taken and roughly tested by the foreman in the following manner: The sample is first ground and treated with boiling water two or three times, the solution being each time poured off; the residue is then washed with hot dilute hydrochloric acid, and the solution decanted and rendered ammoniacal. From the depth of the blue colour thus produced the amount of copper—present as oxide or subchloride, insoluble in water but soluble in dilute hydrochloric acid—is judged.

The solid residue from this is boiled with strong nitric acid; water and ammonia being afterwards added. Should the solution have a blue colour, it indicates that some sulphide of copper still remains undecomposed, and consequently that the roasting is incomplete, and must be continued for a longer period. When all the copper is found to have been converted into chloride, the charge is drawn out on to the paved floor of the furnace house by means of long-handled rakes. The calcined ore is thrown, whilst still moderately hot, into sheet-iron barrows or waggons, and carried to wooden vats, about 12 feet square and 3 feet 6 inches deep, supplied with false bottoms of brickwork, supported upon bricks placed on edge; on this false bottom a layer of cinders is spread to serve as a filter. The tank is filled with ore to within 8 inches of the top, and hot water run in until it stands above the surface of the ore; in the course of two hours a plug is withdrawn from a hole in the side of the tank, between the bottom and the false bottom, and the solution of copper is allowed to run through wooden spouts into precipitating tanks placed at a lower level. The solution of copper obtained from the first five or six washings is of sufficient strength to be at once precipitated, but the weaker solutions obtained from subsequent lixiviations are run into a reservoir, whence they are pumped back and made to serve for washing fresh quantities of calcined ore; so that they ultimately become strong enough to be run to the precipitators. The last portion of copper left in the residues often requires to be extracted by washing with the liquor obtained from the condenser, which, as before stated, is slightly acid. When obtainable, hydrochloric acid, produced in the manufacture of salt cake, may be also employed.

The residue from which all the copper, with the exception of traces, has been extracted, has the following composition:

Analysis of Purple Ore.

Sesquioxide of Iron	96·03	= 67 per cent. metallic iron.
Lead	·75	
Copper	·20	
Sulphur	·33	
Lime	·40	
Insoluble Residue	2·11	
Cobalt, Arsenic, and Chlorine	traces	
Soda	·10	
	99·92	

This, under the name of "purple ore," is employed as an ore of iron, and is much used for making the bottoms of puddling furnaces.

The strong solutions of chloride of copper are run direct from the lixiviating tanks to a series of tanks of similar size known as precipitators; in these, copper is precipitated by scrap wrought iron thrown into the solution, which is heated by a steam-jet. After some hours the copper is completely precipitated and the solution has become colourless. If the whole of the copper has been thrown down, no precipitate will be formed on immersing a clean knife-blade in the spent liquors; if, on the contrary, even a trace of copper has been left in solution, the knife will become coated with a thin red film of that metal.

Instead of scrap iron, a material known as "sponge iron," consisting of that metal in a finely divided state, is sometimes employed for the purpose of precipitation. It is made by heating in a muffle furnace a mixture of purple ore with ground coke; the resulting metallic iron being drawn from the furnace into air-tight cast-iron cylinders, in which it is allowed to cool in order to prevent oxidation. When cold, it is ground in edge mills and sifted through a fine sieve.

When the spent liquors are found to contain no dissolved copper they are run off, and the precipitated copper is shaken free from the iron and carefully washed on perforated cast-iron plates, through which it passes, leaving behind any large fragments of iron with which it may be mixed.

The precipitate is spread upon a tiled floor, beneath which a tortuous flue conveys the heated gases from a fireplace, and by this means it is dried until it contains from 8 to 10 per cent. of moisture. It is now ready, either to be smelted upon the same works, or is packed in casks for delivery to an independent smelting establishment. At the time of delivery of a parcel of precipitate, the amount of water present is determined, in the presence of representatives of both buyer and seller; the weight of water present in the whole parcel is deducted from the gross weight, and the net weight employed as the basis on which to estimate the value of the parcel; all assays being made on dried samples.

The percentage of copper present is determined by fire assay, by two independent assayers, one acting for the seller and the other for the buyer, and the average of the two results is usually taken as a correct representation of the produce of the precipitate, known as the "agreed assay." The produce generally amounts to from 69 to 73 per cent. of fine copper; but by humid assay the percentage is found to be from 72 to 75 per cent.

Mechanical Calcining Furnace.—A modification of the reverberatory furnace, having for its object the replacement of manual labour by mechanical arrangements, and the more perfect calcination of the ore than is generally practicable in hand-worked furnaces, has been introduced by Mr. Thomas Gibb, of the Bede Metal Works, Newcastle-upon-Tyne. The furnace is reverberatory, the hearth being formed of a circular pan, sixteen feet in diameter, made of boiler plate and lined with fire-brick. This pan is carried upon radial wrought-iron girders, fixed to a central cast-iron spindle, which works in a foot-step, and is kept in position by a collar at the upper end, the latter being fitted with brasses, and supported in its place by four cast-iron stays from the ground. The pan is caused to revolve on its own plane on the central foot-step, by means of an endless chain passing around a grooved sheave fixed to the bottom. The hearth is traversed from centre to circumference by a cast-iron plough made to reciprocate by being attached to a cross-head running in a guide, and worked by the same shaft which supplies driving power to the furnace. The speed of the circular hearth and plough is so adjusted that the plough, during any revolution of the hearth, does not travel more than its own breadth. The furnace is charged by means of a hopper, and is discharged by a set of parallel iron plates, which are arranged obliquely across a radial line of the circle on the opposite side of the hearth from the plough. These plates are rigidly bound together at top and bottom, and suspended by a chain, so that they can be raised out of or lowered into the furnace through a slit in the roof, which is kept closed during the roasting of the charge. When the discharging plates are let down, each throws the ore carried against it by the revolution of the hearth towards the circumference, into the path of the next outward plate, by which it is again propelled outwards until it reaches a door plate, which throws it over the edge of the furnace on to the floor.

The working of this furnace, taking it as ready for charging, is as follows: The hearth is kept continually revolving, and the charge, consisting of 5 tons of crushed ore mixed with salt, is run into the furnace from the hopper, and at the same time levelled by the discharging plates suspended at about 8 inches above the hearth. The plates are then drawn up, and the orifice in the roof closed. The hearth makes two revolutions per minute, and the plough makes its journey in one direction once in seven minutes and a half, leaving the surface of the ore in a spiral ridge or furrow. The motions are so adjusted, that in the return journey the plough travels between the lines described in the former journey, or in the line of the ridge which it formerly made; so that at each journey ridge and furrow are transposed, and a new surface is exposed to the oxidizing action of the heated gases flowing over the hearth. When the ore is sufficiently calcined, usually the case in about nine hours after charging, the discharging plates are lowered into contact with the revolving hearth, and these with the doorway plate throw the ore out in a rapid stream over a shoot.

The advantages claimed for this furnace are, that no manual labour is required, except in firing and adjusting the apparatus for charging and discharging; no skill being needed except such as is necessary for keeping up the fires. It is also found that considerably less salt is required in proportion to the burnt ore, and that the copper is obtained in a more soluble state than in most hand-worked furnaces. The calcined ore contains no chloride of sodium, which is of great advantage if alkali is to be manufactured from the waste or spent liquors; whereas in ore treated in hand furnaces, 2·64 per cent. of salt remains undecomposed, and the "salt cake" or sulphate of soda made from the waste liquors of such a material would contain at least 19 per cent. of sodic chloride. As before stated, the quantity of copper produced by the method of wet extraction has been rapidly on the increase for some years; and at the present time the amount annually produced in this country from cupreous iron pyrites by this process, or by some modification of it, much exceeds the production of the mines of the United Kingdom.

Hunt and Douglas Process.—This process is based upon the fact that oxidized compounds of copper, such as cupreous and cupric oxide, oxychloride or carbonate, are, under favourable conditions, converted into cupreous and cupric chloride, by the action of solutions containing neutral ferrous chloride. The ore, if consisting of natural oxides or carbonates, is ground to a fine powder, and treated with a bath containing ferrous chloride; whilst if the ore contains sulphides, roasting must first be resorted to in order to convert these into oxides. In the case of carbonates or suboxides of copper, roasting is also found desirable; in the former case, for the removal of carbonic acid, and in the latter, for the conversion of cupreous into cupric oxide.

The neutral ferrous chloride is prepared by the action of chloride of calcium or sodium upon ferrous sulphate, and the preparation of the bath, above mentioned, is conducted as follows: 120 lb. of sea-salt are dissolved with 280 lb. of ferrous sulphate in 100 gallons of water. In place of this a quantity of ferrous chloride, containing 56 lb. of metallic iron, may be used. In either case, 200 lb. of sea-salt are next added, and the solution is ready for use, and will be found capable of dissolving about 90 lb. of copper. The finely ground oxidized ores are digested in this bath, with frequent agitation; when the solution is complete, and the liquid has been drawn off, the insoluble residue is treated with a small quantity of hot brine.

The copper present in solution is precipitated by digestion with metallic iron, and is obtained as cement copper. The bath, after being thus freed from copper, contains a considerable quantity of regenerated ferrous chloride, and is employed for the treatment of a fresh quantity of cupreous ore; as, however, there is a slight loss of chlorine by the formation of oxychloride of iron, it becomes necessary to add to the bath at each operation a quantity of ferrous chloride equivalent to this loss. This amounts, for each operation, to about one-eighth of the quantity originally present.

The application of heat is not considered necessary, although the solubility of the oxides of copper is thereby considerably increased.

When the ore to be treated contains sulphides, it is necessary to roast in a muffle furnace, with frequent stirring, until the copper is entirely converted into oxide or sulphate, and, since the latter would consume more iron for its precipitation, it is found desirable to add to the calcined ore a sufficient quantity of finely ground lime, to convert nearly the whole of the copper into oxide; the mixture of calcined ore and lime is then treated with the bath in the usual way.

This process has been successfully worked in America; but although suitable for working ores in localities where salt is expensive, it is doubtful whether it could compete in this country with the older method of roasting with salt.

Extraction of Copper from Pyrites at the Mines.—As has been before stated, a large quantity of cupreous iron pyrites, too poor for exportation, is annually treated at the mines of Tharsis, Rio Tinto, &c., in Spain, where a large proportion of the pyrites employed for the manufacture of sulphuric acid is obtained. The mode of operating is as follows: The pyrites is broken into fragments of the size of the fist, and piled upon brushwood, the outside of the heap, which contains about 100 tons of ore, is covered with the small ore, detached from the mass in handling, and from which it is separated by screening; the heap is fired by means of the brushwood, and continues burning for a period of from six to eight months, at the expiration of which time the copper has, to a considerable extent, been rendered soluble. From these heaps the ore is carried to tanks, in which it is subjected to a lixiviation with water, which removes the whole of the copper, with the exception of about one-half per cent. The liquors draining from the lixiviators contain sulphates of iron and copper; the copper is precipitated in the form of cement copper, by allowing the liquors to flow over bars of pig iron, arranged in hollow piles in the precipitating tanks.

The large quantity of ferric sulphates present in the copper liquors causes a considerable waste of iron, three parts of that metal being required for the precipitation of one of copper.

The copper left in the spent ore is not entirely lost, the refuse is piled in large heaps, "terreros," and watered from time to time; the drainage carrying with it a small quantity of copper, is conducted to precipitating tanks in the usual way. These refuse heaps, which are of enormous size, continue to yield cupreous water during many years.

BRASS FOUNDING.

By Walter Graham.

The origin of the word brass is not free from obscurity. The resemblance which it bears to the colour of flame gives ground for supposing that it is derived from the Spanish, "brasas," which means coals on fire; or "abrazer," burning or inflaming. The word has also been attributed to the Portuguese "braza," expressing that which has brightness of colour; also the Saxon "bræs," the Cornish "brest," the Welsh "prês," and the Irish "pras"; although the connection is, in either case, not very clear.

But the meaning of the word admits of no doubt. It signifies an alloy of which copper is an important constituent, the other elements being chiefly zinc, tin, and lead.

It is therefore the art of alloying copper with other metals, and moulding it into shapes and forms adapted to the many wants of man, with which I have to deal in the present article.

Of all the arts there is perhaps not one so ancient as that held by the artificer in brass, for from the earliest time every country has had its brass workers. Nearly six thousand years ago the metallic strata which cropped out from the mountain sides *were studied*, fired, hammered, and rendered submissive to the indomitable will of the great father of all metal workers, Tubal-cain (the Hwang-te of the Chinese). This extraordinary man gathered around him a school of artificers, and unceasingly laboured to make them acquainted with the properties of brass, the mode of its reduction, and its application to his many inventions.

In early Hebrew writings we have such expressions as "mountains of brass," "dig brass from the hills," "brass molten from stone," from which some infer that the ancients obtained it in a native form, while others believe that they were aware of some alloying process.

We are familiar with the word in its frequent applications to *brass* armoury, statuary, gods, bells, gates, vessels, and the like. It was a serpent of *brass* which Moses raised in the wilderness; they were vessels of *brass* which Hiram made for Solomon's temple. It was of a "*brass* precious as gold" that Ezra's vessels were made for the temple at Jerusalem; and it is of *brass* (or bronze) that the swords, armour, tripods, and cooking utensils are composed which were exhumed by Mr. Layard from the ruins of ancient Nineveh.

Heathen mythology, too, favoured the brazier's art. Brass or bronze statues were made in large quantities, and on them often depended the wealth of a state. Such cities as Athens, Delphos, and Rhodes, had each of them at least three thousand statues. The famous Colossus in the latter town, erected to Apollo three hundred years before Christ, measured 105 feet in height and took twelve years to execute. It cost 300 talents, which at the value of 396*l.* per talent, comes to the enormous sum of 118,000*l.* sterling. This statue was destroyed by an earthquake fifty-six years after its erection, and remained buried among the ruins for over nine hundred years, when it was sold by the Saracens to a Jew, who extricated from it nine hundred camel loads of brass.

During the early ages of Christianity we find brass bells introduced into the church towers, to call forth the people. In the year 400 they first pealed from the church at Nola, in Campania. In 670 they were introduced into the monastic societies of England; and in 870 Croyland church obtained its great bell, and subsequently its chime of six. But before the Christian bells were allowed to utter their sounds of joy or sorrow, the Church baptized and named them, made signs of the cross upon them, and imparted its blessing on the alloy.

Previous to the Reformation our churches were garnished with many monumental tablets of brass, which our forefathers obtained from the Netherlands, but which unfortunately suffered severely from the irreverent hands of the destroyer. Fortunately a few still remain to illustrate the work of 1277 to 1507. Specimens may be seen at Rutland and at Warwick, with their giant portraitures and angular letters.

About the reign of Henry VII. the English began to move in the art, and we have an example of the period in the brass railing round that king's monument in Westminster Abbey.

We owe the introduction of our general trade in brass to the wisdom of Queen Elizabeth's advisers, who invited and encouraged several Germans to this country to instruct us in the art, and accordingly

Daniel Houghsetter and Christopher Schutz arrived in England in 1565, with upwards of twenty German workmen.

In 1649, Messrs. Momma and Demetrius, both Germans, erected brass works at Esher, in Surrey, at a cost of 6000*l.*; but English taste was not prepared for so large an undertaking at that date, and so the adventure unfortunately proved a failure and ruined both gentlemen—a result not uncommon in pioneering enterprise.

They were succeeded in 1678 by the erection of the celebrated works of Prince Rupert for manufacturing yellow brass; by the Temple Water-mill Works, at Hackney, for making brass cannon; by the Baptist Mills, at Bristol; by the ancestors of the Darbys, of Coalbrook-dale (at whose works it is supposed England first began her foreign trade); by Mr. Thos. Oswin, in 1710; by the brass foundry in Dublin, and many others.

Up to the year 1800, many patents were granted for improvements in the process of alloying the metals. The Germans had taught us to fuse calamine (carbonate of zinc) with copper; but the improvers desired to fuse the metals in a pure state, so that the old process gradually became obsolete, and the new one universal.

By the commencement of the present century, Birmingham had become the recognized seat and centre of the brass trade, on account, no doubt, of its proximity to the trades and markets most in want of its productions, and of the ease with which all the requisites could be obtained for carrying on the work to an unlimited extent.

At this period, the trade was mainly that of cabinet brass foundry, such as locks and hinges, knobs and buttons, casters, and roller furniture, nails and screws, curtain bands and drawer handles, sash lifters and fasteners, hat pins, and poles, &c., but these were soon succeeded by the manufacture of brass candlesticks, scuttles and kettles, knockers, bell pulls and cranks, and a world of household sundries.

A new branch of the trade sprang into existence with the invention of the steam engine, followed by the other great engineering works which have added so much to our domestic comforts, such as the supply of gas and water, and these alone developed the trade to double its former output.

In 1831, Mr. Thos. Pemberton purchased the business of the Birmingham Joint-Stock Company, and continued it with eminent success for twenty years; indeed, his patterns may be seen in nearly every ironmonger's shop throughout the kingdom.

The introduction of the penny postage added much additional work to the brass founder, by the demand which took place for letter balances.

It is difficult to collect the exact state of things at any particular date, and still less at regular periods; but so far as I can gather, the following appears to have been the progress of the trade, in round numbers:

In 1800, the number of employers was 200, of workpeople 2,000
1825 " " 900 " 9,000
1850 " " 1000 " 10,000
1873 " " 1500 " 15,000

In Birmingham alone there appear to have been fifty employers in 1800; one hundred and fifty in 1825; and about two hundred and fifty at the present time.

Many large brass founders are scattered over the country, altogether independent of the Birmingham trade, as in London, Liverpool, Glasgow, and Leeds.

In 1800, Birmingham consumed about 1000 tons of brass. In 1825 it manufactured about 10,000 tons; in 1850, 20,000; in 1865, 38,000; and at present about 44,000 tons, which represents something like three million of money.

Our exports in 1799 are said to have been 3851 tons 13 cwt.

				£
In 1872	they were	13,956 tons,	value	1,241,012
1873	„	15,715	„	1,490,880
1874	„	19,294	„	1,796,525
1875	„	18,394	„	1,574,780

This is exclusive of ordnance, three-fourths being used for ship-sheathing.

Properties.—With the exception of iron, no metallic substance has acquired so much importance in the arts and manufactures as brass, on account of its numerous and varied properties. At times we find the characters of the alloy differing as widely as the poles from those of the metals of which it is composed. In other cases, the alloy possesses almost a true mean of the properties of its component; while a third group is neither a mean nor an antagonistic.

Such diversity, however, has imparted much value to the alloy, and given it that wide range of application which it possesses.

Commercial brass is a non-chemical substance, that is to say, it is not an atomic compound, as the metals unite in all proportions. Yet we must believe in a true chemical alloy, for the metals will unite in atomic proportions. In such a state it is said to be isomorphous with copper, and to crystallize in octahedrons. According to the proportion of its ingredients, so is its specific gravity, which may be taken from 7·5 to 10·0, but is reduced by heat to a point inferior to that of the mean of its components.

Brass is, of course, fusible, and in process of remelting loses in weight 4 to 6 lb. per cwt. by volatilization, especially of the lighter metals. It presents the same indication of malleability common to all malleable metals, namely, that of becoming pasty before it is liquid. Ordinary yellow brass fuses at 1835° Fahr. or 1021° Cent., while brass of other proportions varies from 1000° to 1900° Fahr.

It is cohesive, in some cases to a greater, and in others to a less degree than the mean of its components: 1 part of tin with 6 of copper being the proportion which yields the greatest cohesive force. Heat reduces this cohesive force, as it does in all other alloys and metals.

Brass expands by heat $\frac{1}{535}$th of its length, is malleable and capable of being rolled or beaten into any required form. Heat favours its malleability, and under proper conditions it can be rendered so thin that 52,900 plates can be put within the space of 1 inch. It is ductile, or capable of being drawn into wire and tube, without being torn asunder. Heat, however, is unfavourable to its ductility.

Brass is tenacious beyond all metallic bodies, excepting iron and copper; but if the tension is continuous, a singular molecular change takes place which totally unfits it for work subject to strain, such as tie rods or chains for suspending weights. The alloy becomes, so to speak, rotten. It is singular that the Birmingham brass founders hang nearly all their balance weights for gas lustres with brass chain, a practice which is well known to be unsafe.

Brass possesses density to a remarkable extent, and is second only to iron in resisting the force of compression.

It is also sonorous, emitting sound in the highest degree, when the components are from 2 to 5 parts of copper to 1 part of tin.

Under proper conditions it is springy and elastic, is a conductor of heat and elasticity, evolves heat on being liquefied, is incorrodible in water, has a high metallic lustre, is susceptible of polish, and has a range of colours from red to orange, yellow, grey, and white.

Brass which contains not more than 50 per cent. of zinc exhibits a reaction towards copper in the voltaic current, and does not precipitate the salts of copper; while that which has an excess of zinc decomposes copper salts, being thereby converted into pure copper. Such brass likewise dissolves completely in acids which have no action on copper alone. Hydrochloric acid reddens it, while ammonia whitens it: the one attacks the zinc; the other the copper.

Those who are interested in the testing of brass will find drawings and descriptions of the different apparatus, in "An Account of Experiments on the Strength and other Properties of Brass for Cannons,

&c.," published in 1856 by Trübner, London, pp. 307–321.

Composition.—Brass is either a mechanical or chemical mixture of two or more metals, run together when in a state of fusion. Copper is always present, but the companion metal may be either zinc, tin, or lead. These three metals give rise to three groups of brass, namely, the zinc, tin, and lead groups, which are as follows:

THE ZINC GROUP.

5	parts of copper with	1 of zinc yield	rich sheet brass
4	,,	,,	pinchbeck brass
3	,,	,,	Dutch brass
2	,,	,,	ordinary yellow brass
1·75	,,	,,	pale coloured brass
1·50	,,	,,	ship sheathing brass
1·25	,,	,,	dipping brass
1·00	,,	,,	hard solder

THE TIN GROUP.

20	parts of copper with	1 of tin yield	a red alloy with odour and taste
16	,,	,,	,, ,,
12	,,	,,	,, ,,
10	,,	,,	alloys of strength
9	,,	,,	,, ,,
8	,,	,,	,, ,,
7	,,	,,	,, ,,
6	,,	,,	,, ,,
5	,,	,,	,, ,,
4	,,	,,	alloys of sound; bell metal
3	,,	,,	,, ,,
2	,,	,,	,, ,,
1	,,	,,	alloys of reflection
0·5	,,	,,	,, ,,
0·3	,,	,,	,, ,,

The Lead Group.

4 parts of copper with 1 of lead, 1 part of zinc and $\frac{1}{7}$ of tin, yield best cock metal
2 " " 1 part of tin, yield best cock metal
1 " " yield tap and pot metal
0·5 " " " "
0·4 " " " "
0·3 " " " "
0·2 " " " "
0·1 " " " "

The different proportions employed in the formation of brass give rise to different colours in the alloys, the composition of which is as follows:

> Red brass, of any proportion between 7 to 20 parts of copper and 1 of either tin or zinc, or between 4 to 8 of copper and 1 of lead.
>
> Gold-coloured brass, of any proportion between 4 to 6 of copper and 1 of zinc.
>
> Yellow brass, between 1 to 3 of copper and 1 of zinc.
>
> Grey brass, between 2 to 5 of copper and 1 of tin.
>
> White brass, between 1 of copper and from 1 to 4 of tin; or between 1 of copper and from 2 to 3 of zinc; or when arsenic is added to copper.

Iron is sometimes introduced into the composition of brass, as in the Fontainemoreau compounds and the Japanese bells.

Tin renders the compound hard; and lead in small quantities makes the castings sharper than that made from an alloy in which it is not present.

In breaking asunder a bar of brass, it will be found that the metals, after they have been mixed and poured, separate to a greater or less extent, the heavier metal being found in greater proportion at the lower side of the casting. If the brass contains lead, that metal may sometimes be found oozing out of the alloy.

It is usual for brass founders to manufacture their own brass to suit their requirements, although ordinary yellow brass can be purchased in ingots ready for melting.

Manipulation.—Formerly, and even within my own memory, the mode of combining the metal to form the alloy was by dressing and reducing carbonate of zinc, and smelting it with copper for twenty-four hours, in crucibles which were enclosed by dozens at a time in horse-shoe furnaces.

Modern furnaces are constructed in two ways: first, by placing a wrought or cast iron cylinder (about 2 feet in diameter by 4 feet long, with a part cut out for the flue) on end, 2 or more feet up from the hearth, and lining it with fire-clay bricks, so that the internal diameter is from 8 to 12 inches, according to the size of the crucibles to be used. The bottom is formed of common furnace bars, the air being admitted and the ash removed through a cave which communicates with the outside of the building. The mouth of the furnace is closed by a cast-iron loose cover. A 5-inch flue is formed within a brick of the top plate, which leads into a main flue, conducting the contents into the chimney stack, the former being fitted with a regulating damper.

The second mode of construction is the square system.

Cast-iron plates, resembling tank plates, 3 to 4 feet wide, and the same length as that of the furnaces, are placed 4 feet apart, and bolted together at that space by strong tie-rods 2½ feet apart on the length of the plates, and about 1½ foot apart on the depth. The furnaces are then built of 18-inch work, or otherwise, according to requirements, in the same manner as described above, except that the internal space is square instead of cylindrical.

Each furnace is made to contain a single crucible, and so long as castings are confined to small sizes, the contents of a crucible are usually enough for a casting. We are not, however, always content with small castings. The screw or propeller of a steamer may sometimes weigh tons, and consequently, the contents of one crucible are but a drop in the bucket. When, therefore, quantity is wanted, the founder resorts to either of the following methods:

First, he can use a number of furnaces like those just described, close the cave, and introduce tuyeres under each furnace, through which he can send a blast from powerful fanners, driven by the engine, which greatly increases the melting power of the furnaces. As the mould is filled from one crucible, the others are gradually poured into the acting crucible, and so a continuous flow of brass is kept up to feed the mould.

Secondly, he can melt in a reverberatory or a cupola furnace; although such a plan is very wasteful, and, if possible, should be avoided. The furnaces suffer a great deal of destruction from the action of the fire, and out of every dozen furnaces, two, or perhaps three will be usually under repair.

The crucibles or pots in which the metals are melted are of two kinds, the burned and unburned. Of the former, the Hessian, the Berlin, the Stourbridge, and Mr. Anstey's, are oftenest employed. The latter is a simple compound of 1 part of pure fire-clay with 2 of black-lead, worked up with water on a potter's wheel, or compressed into a mould, upon a mandril. These blue-pots, as they are termed, are carefully kiln dried, and found to answer so well that they have almost become universal. They stand sudden changes of temperature, and do not allow liquids or gases to pass through them, and these are most important properties in crucibles.

The furnaces having been kindled (coke being the fuel employed), the crucibles are placed in them, bottom upwards, and allowed to remain till they become red hot, for if put in otherwise, they would be sure to crack and fly in pieces. When red hot, they are turned mouth upward, and a charge of copper only inserted in each; the fuel is made up all round the sides of the crucibles, and a few pieces of hard coke placed on the mouth of each, the dampers regulated, the furnace mouths closed, and the whole allowed to remain till the copper is melted. The other portions of the charges, zinc, lead, or otherwise, being broken into small pieces, are placed at the mouth of the furnaces to heat. When the copper is melted, the other metals are added gradually, in their hot state, so as not to chill it. Careful management is required with zinc to prevent volatilization. As each piece is let down by tongs into the crucible, it is plunged under the surface of the copper and held there till it melts. Great danger attends the introduction of cold or damp matter into liquid copper. The metals having become liquid, the contents of the crucibles are carefully stirred with a hot brass or iron rod, so as to incorporate the metals as much as possible; for, mix as we may, the light metals will volatilize, and the heavy ones subside to a greater or less extent.

If it is desired to form the brass into ingots, the contents of the crucibles, which are raised from the furnace by clamp-tongs, are poured into iron moulds, heated and prepared for the purpose; but if the brass is not intended for ingots, it is poured direct into ordinary moulds, which is the general practice and saves the expense of remelting.

A little salt cake thrown into the crucible at the moment of pouring, assists to raise all impurities to the surface of the alloy, which is skimmed off by the workmen before or at the time of pouring. This process is one which requires care to prevent the passage through which the molten alloy is run being choked by too rapid pouring; but free exit must be allowed for the air which fills the cavity, and for the gases which are formed in the course of pouring.

During the process the chamber is filled with metallic fumes of a very unhealthy nature, which the greatest care, even with the use of respirators, cannot prevent being inhaled by the workmen, and this makes them subject to a kind of intermittent fever, known as brass ague. Of course, in well-regulated establishments a good deal is done to mitigate the evil by a well-proportioned room and good ventilation. In pouring, care must be taken to turn the small castings first, when the alloy is hottest. The larger ores are run with the "after metal," as it is called, that is, with the cooler alloy. If time is not an object, ordinary work should not be opened till the alloy is cool, as the castings thereby become improved by the process of slow cooling, and, in fact, are annealed.

When opened, the castings are conveyed to the dressers to be cleaned and trimmed, while the moulding boxes and sand are returned to the moulding shop, a large roomy building, with accommodation for sands suited for the various purposes of the trade. The general stock is kept in pits, while the sand in use is contained in long deep troughs at which the men work. They are divided into compartments of 10 feet or so, which is the allotted "tub" for a man, and each tub has a pair of sliding bars or bearers, to support the "flasks" or boxes in which the matrix is formed.

One of the flasks being placed on a flat 1¼-inch board, on which are the patterns to be moulded, the moulder sprinkles over them some fine dry sand, known by the trade as "parting," and then adds a little fresh, unburnt, moulding sand, called "facing," till the patterns are covered to the extent of half an inch; and lastly, shovels in moist sand from the trough, and rams it tight with an iron rammer, till the flask can hold no more. It is then scraped flush, and pricked with a pointed wire, to give vent to the gas formed in pouring in the alloy. Another flat board is taken and placed on the top like a lid, and the boards and flasks are then turned right over; what was the bottom board before being removed, and showing the patterns embedded in the sand. The face is now cleaned and freed from imperfections, and those patterns which are only half embedded receive their counterparts.

The next operation, namely, that of withdrawing the patterns, is done by slightly tapping them all ways, to relieve them from the sand, and then with a steady hand raising them from the impressions. If this operation disturbs any of the sand, the mould must be repaired; and any portions of the intended castings which are to have holes or hollows left in them are now supplied with pieces of well-baked sand, called cores, prepared for the purpose. The moulder having fixed them, cuts passages or channels of communication between the patterns and the exterior of the flask for the admission of the molten alloy. The faces of the mould are now dusted over with finely ground wood charcoal, or pease meal, and the flask closed. An additional facing is often applied to the mould by a deposit of soot on it from burning pitch torches. The castings produced from these moulds are known in the trade as "faced," and bring a higher price than the others.

In ramming the flasks, some art and practice are required. If rammed too hard, the generated gases do not escape freely, and air holes in the castings are the result; if too soft, the pressure of the alloy causes swellings on the castings. In either case they are useless. When large quantities of castings are required, the founder resorts to machine rather than to hand moulding. A machine consists of a table, on which is fixed the whole or half pattern, as the case may be. The flask is rammed up on it, as described in hand moulding, and by means of a screw or lever the patterns are drawn with mathematical accuracy from the sand through the table. The operations of dusting and stoving are conducted as already described. The other flask is treated exactly in the same way on a companion machine, and the pair are then closed, cramped, and taken to the caster. In principle these machines are the same as those employed by iron founders for moulding railway chairs, flow metal, sash weights, fire-bars, and the like, and are capable of turning out a vast amount of work.

Castings are also produced for special purposes by another method, known as chill moulding. The mould in this case is either wholly or partly made of iron. Metals and alloys run into or upon iron harden the surface by contact, and hence bearings for machinery and goods to stand compression are, or should be, cast by this method.

The surface of the iron mould is kept very clean, and is either polished with black-lead or coated with oil, or a mixture of red-ochre and albumen.

A similar process is adopted for casting blocks of brass, which are to be rolled into sheets, except that the moulds are made of marble. Each mould of this kind consists of two huge marble blocks, 5 feet 6 inches long by 3 feet wide and 1 foot thick, and are placed one above the other. The top one is hung by an apparatus which enables the workmen to remove it with ease and replace it at pleasure, other appliances being attached to the sides of the marble for regulating the thickness of the blocks to be cast. The surfaces of the marble are kept clean and smooth, and, before each casting, are coated with a thin layer of prepared loam. The sides and ends are made up with ordinary sand, and a sort of hopper, thickly coated with moulder's sand, is attached for the purpose of admitting the alloy to the mould. Large symmetrical castings, such as church bells, can often be made without a pattern, properly so called. The process is termed "loam moulding," and consists of grinding wet loam and sand in a mortar mill, and plastering a rough pile of brickwork with the mixture. In the centre is placed an upright spindle of iron, on which is hung a wooden board, cut in profile to the *inside* shape of the article to be made. It sweeps round the plastered brickwork, and, when the shape is perfect, the mould, which has been built on a carriage, is placed in the stove to be thoroughly dried, then coated with a wash of charcoal and water, and again dried. Another coat of loam mixture is put on, representing the thickness of the intended casting, and a second sweep-board, cut in profile to the *outside* size of the article, is made to swing round on the centre spindle till a proper and perfect form is got. This is dried and coated with black-wash, as described above. When these operations are finished and the mould cooled, a large iron flask is placed over it and filled up with moulder's loam and sand, tightly rammed. The flask is afterwards raised from the mould, and the impression made as smooth as possible with bright iron tools, prior to a removal to the stove to dry the loam, which is also black-washed and again dried. The second coating of loam mixture, which represented the thickness of the article, is now taken from the first one, the purpose for which it was intended being accomplished. The first coating is carefully examined, any imperfections repaired, black-washed anew, and provision made for the escape of the gas generated during the process of pouring. The flask is then fixed to the carriage, and the whole is run into the casting shop to receive the liquid alloy.

It is of great importance in the art of founding that the proper sands are used for the different purposes to which they are applied. The great bulk of moulding sand used in this country is obtained at Birmingham, Belfast, and Hampstead, and is highly silicious. Sands containing more than 6 per cent. of metallic oxides, lime, and magnesia, are objectionable, as the heat of the alloy, in pouring, fuses such materials, gives rise to a large amount of gas, and is certain to produce bad castings. These sands are adhesive when they contain a small amount of water, and on that account do not succeed when quite close to the pattern. It is therefore necessary to sprinkle very dry and fine river sand over it before using. The cores are made from a ground rock sand, known as rotten rock.

The cast plates formed under marble, as before described, are first subjected to pressure between heavy rollers in the department known as the mill. The first machines through which they pass are called the "breaking-down rollers," which reduce their thickness and increase their length. They are then heated to blood redness in a reverberatory furnace, and gradually cooled, because the plates have become too hard for further rolling. They are again passed through other rollers till they again become too hard, and this process is repeated till the required thickness is arrived at. The plates are then dipped in dilute sulphuric acid, known as the "pickle bath," and afterwards well washed in water and dried. The plates known in commerce as "latten plates" obtain a further rolling between polished rollers, to impart to them a brightness of finish.

During the rolling, scales, blisters, and other imperfections make their appearance, not from any fault in the rolling, but in the casting. Such plates are set aside, and sold at a reduction, under the name of "spilly plates." The perfect ones are known as sheet brass.

Brass intended to be converted into wire is rolled by the method just described, to the thickness of three-eighths of an inch, and then cut into strips by rollers made for the purpose, termed "slitting rolls;" and these strips are again placed between grooved rollers till the length becomes inconvenient. Like the sheets, they require annealing. They are then passed through a series of doubly tapered holes, nicely made in steel blocks, on a "drawing bench," which consists of an endless chain in motion, carrying with it the thin end of the brass which is passing through the steel block. Through a succession of holes, each one less than its predecessor, the brass travels till it is reduced to a comparatively slender thread, when it is rolled round a drum as it passes from the reducers. The drum is placed under the bench or at its end, and is revolved by a spindle and beveled wheels. It is necessary to anneal repeatedly in the course of drawing. The operation can be stopped at any point, so as to give out the wire at a required thickness.

It will be seen that in the process of drawing, the whole length of the wire is passed through one hole or reducer before it travels the next one; and it has often occurred to me that the waste of time which thus takes place might be saved by a machine, which would allow of the wire passing through as many reducers as can be done between the annealings.

It is usual to make thirty-six different sizes or diameters of wire. The thickest, or that known as No. 1, is about one-third of an inch in diameter (correctly, it is decimal thirty-one of an inch). The thinnest is ·004 of an inch. Each size has a standard measurement or gauge recognized by the trade, and known as the "Birmingham wire-gauge."

In the art of brass drawing there is a more important department than that of wire, namely, that of drawing tubes. The brass, rolled in sheets to the thickness required, is cut into long strips in the slitting rolls, according to certain diameters. The strips so cut are first passed through the furnaces where they are made red hot, and, on cooling, travel through grooved rollers, the one concave, and the other convex in the grooves.

These rollers turn up the edges, which are now filed clean, a mandril being placed into the semi-formed tube, and the edges malleted together or passed through another pair of rollers. The mandril is then withdrawn, and they are bound together with wire or binders every one or two inches. They are next charged inside with wet borax and spelter solder, and conveyed to a class of men known as "burners," who work the tubes over intensely heated coke fires, reduce the solder, and so cement the edges. The tube thus formed is now dipped in a bath of dilute sulphuric acid, and afterwards well scoured with sand and water, and when dried is sent through a reducer, a fraction less than its own diameter, on the draw bench. The outside is thus made smooth and clean, but the inside is left rough. The tubes just described are the ordinary brass tubes of commerce, and are sent out in lengths of from 12 to 18 feet. Having passed over the burner's fire, they are soft, and capable of being bent into almost any form without risk of breakage.

The roughness inside the ordinary tubes renders them unfit for such purposes as telescope work, the tubes having in such cases to slide one inside another. Such tubes are drawn inside as well as outside, on a mandril, and by repeated drawing, annealing, and pickling, a beautifully smooth, thin, and bright surface, outside and in, is obtained. Sometimes, however, these tubes are hard and elastic, if great care is not taken with them in repeated annealing.

The locomotive requirements of the present age have called forth another make of tubes not formerly attempted in brass. Tubes with a soldered seam do not stand the pressure of steam, and therefore it became necessary to draw them solid. After many attempts, this succeeded about the year 1838, since when they have been so largely made, that every engine running on our railways contains some hundred and fifty of these tubes in its boiler.

Another form of tubes, called "tapered tubes," has attracted a great deal of thought and experiment. Many patents have been taken out, and many failures have occurred. At last the object was attained in a most simple manner, viz. the sheets were cut to form, and bent round a tapered mandril, bound and soldered as already described, and then passed with an internal mandril through a thick draw-plate made of soft metal, which yields to the shape and gives the proper amount of pressure to produce a smooth outside, while the mandril keeps the inside all right.

Common stair and picture rods are made by drawing very thin tubes over iron bodies. This process imparts strength to the articles with a very small amount of brass.

Fluted or reeded tubes are drawn through plates cut to the form of the flutation, and over either plain or cut mandrils. These tubes may be made square, triangular or otherwise in section.

The twisted or cable form of tubes is made of very pliable brass by drawing through plates formed with the threads of the spirals, very much like nuts. They are otherwise made by stamping the flat strips, turning them over, and soldering the edges together.

Ornamental tubes are produced in a variety of ways, but principally by impressing the pattern on the strips of brass, by passing them through rollers which are cut to the pattern required. When the rollers are plain, patterned zinc is placed between two strips, and passed through the rollers together. In this way some beautiful patterns have been made from natural objects. When so impressed, the strips are sent through, as already described, pickled in dilute sulphuric acid, scoured, washed, and dried.

When large quantities of thin brasswork are wanted, the founder resorts to the process of stamping between steel dies. The machine employed for this purpose consists of a heavy weight, which is let fall from a height upon the top die, the principle of the machine being nearly that of the pile-driving apparatus, so common at our docks and wharves. Taking advantage of the ductility of brass, impressions are thus easily made in relief, the chief cost being in the dies. Much of the brass stampings require deep indentations, and in such cases the process must be conducted somewhat gradually to prevent cracking or rending. A series of dies is therefore used, and a number of brass plates acted upon at one time. The process of annealing from time to time is also necessary, as the plates get very hard by repeated concussion. At each stroke of the hammer one or more plates are withdrawn from the lower, and as many new ones added to the upper part of the bundle of sheets between the pair of dies.

Many articles require to be stamped in pieces, and afterwards soldered in the manner described in making tubes; as, for example, balance weights for gas lustres, vases, pole ends, &c.

The goods all leave the stamping hall in the discoloured state which they obtain in the process of annealing.

Having mentioned the leading processes for brass in the rough, I shall now glance at a few of the principal methods for finishing the goods.

Nearly every article requires more or less *filing*. It is mostly done by hand labour with ordinary float, bastard, and smooth files, of sundry sizes. A few files are of different shapes from those commonly found in a retail shop. Brass tubes and such like articles have for many years been filed by a float machine, as any plain or round surface can be acted on by it, and I strongly recommend it for its economy, where it can be constantly employed. It resembles a little planing machine, which, by the way, is in itself invaluable to an extensive brass founder.

As to *turning*, so much work of a multifarious nature is performed on the lathe that I must refer the reader to books treating of that subject alone. The brass founder has to perform all kinds of plain, spherical, and ornamental turnings, which necessitates a complication of lathes and tools. In the turner's hand the tool must never be allowed to rest, but must have a proper rotation and a correct inclination to avoid furrowing the work.

In the lathes, too, the turner makes the screws on the goods, where required, by a peculiar kind of short-toothed steel comb with a strong back. This comb is caused to travel backwards and forwards on the article operated upon till the screw is cut. The ordinary process of screwing by taps and dies is little used by the brass founder.

The process of *spinning* is very clever. By it, glass, china, and wood knobs and roses are attached to their brass fittings. If the reader looks at a china door or shutter knob, he will, if unacquainted with this process, be puzzled to understand how the glass, china, or wood has been inserted into the brass. The brass mounting is first formed like a flat saucer, into which the glass or other article is easily inserted. The articles being fixed in a lathe and set in motion, the workman applies to the thin edges of the saucer socket a certain amount of pressure by means of a tool called a burnisher. This pressure on the rotating body has the effect of turning over the edges of the socket upon the glass or china. Optical lenses are often mounted in the same way.

The process is extensively carried on with brass lock, shutter, and other knobs. These are generally cast, each in two hollow pieces, and are spun together so as to form one united article.

By the processes of *chasing* and *matting*, sharpness of detail is imparted to the work, and the surface rendered more beautiful. The operations are performed by a number of little hammers and chisels, and are so well known in silver work that they require no lengthened description in this place. Cheap classes of goods are not treated by either of these processes.

Burnishing is a process which imparts great lustre to brasswork, as may be seen on picture rods, pole ends, &c. The tool which is used is of hardened steel, polished as highly as possible, and round or elliptical on its face. This tool is kept moving along the surface of the brass in intimate contact and under considerable pressure, just as if the brass was drawn through a highly polished steel die. To give facility and motion, it is lubricated with sour beer. Of course, the work first requires to be finished as highly as possible before the burnishing begins, as any defects could not be corrected by the burnisher. A considerable portion of work is only partially burnished, so as to give relief to the "dead" or dull surface; as, for example, curtain bands, pole ends, stove mountings, &c. The burnishers must never be allowed to get the least tarnish, and are cleaned with crocus and oil, on buff leather.

Polishing.—A large variety of goods, such as door and window plates, mouldings, astrigals, ship work, &c., is sent out of the brass foundry without any further finish than that of simple polish. The goods being well and smoothly filed and the file marks taken out by emery cloth, the work is rubbed up with crocus and oil, and finished with dry whiting or rottenstone. Whenever it is possible, this latter is done on buff-leather revolving wheels, which is better and cheaper than hand labour.

It will be understood that this work tarnishes very rapidly on exposure to the atmosphere, and requires daily cleaning, for which a solution of oxalic acid or polishing paste is the most efficacious.

Bronzing.—To prevent the every-day rusting of brass goods, the trade has long resorted to means for protecting the surface from the action of the atmosphere, the first plan of which is to force a change to take place. Thus, if brass is left in damp sand it acquires a beautiful brown colour, which, when polished with a dry brush, remains permanent and requires no cleaning. It is also possible to impart a green and light coating of verdigris on the surface of the brass by means of dilute acids, allowed to dry spontaneously. The antique appearance thus given is very pleasing and more or less permanent. But it is not always possible to wait for the goods so long as such processes require, and hence more speedy methods became necessary, many of which had to be further protected by a coating of varnish. Before bronzing, however, all the requisite fitting is finished and the brass annealed, pickled in old or dilute nitric acid till the scales can be removed from the surface, scoured with sand and water, and dried. Bronzing is then performed according to the colour desired; for although the word means a brown colour, being taken from the Italian "bronzino," signifying burn brown, yet in our commercial language it includes all colours.

Browns of all shades are obtained by immersion in solutions of nitrate or the perchloride of iron: the strength of the solutions determining the depth of the colour. Violets are produced by dipping in a solution of chloride of antimony, or of permuriate of iron. Chocolate is obtained by burning on the surface of the brass, moist red oxide of iron, and polishing with a very small quantity of black-lead.

Olive-green results from making the surface black by means of a solution of iron and arsenic in muriatic acid, polishing with a black-lead brush, and coating it, when warm, with a lacquer composed of 1 part of lac-varnish, 4 of turmeric, and 1 of gamboge.

A steel-grey colour is deposited on brass from a dilute boiling solution of muriate of arsenic; and a blue, by careful treatment with strong hydrosulphite of soda.

Black is much used for optical brasswork, and is obtained by coating the brass with a solution of platinum, or with chloride of gold mixed with nitrate of tin. The Japanese bronze their brass by boiling it in a solution of sulphate of copper, alum, and verdigris.

Success in the art of bronzing greatly depends on circumstances, such as the temperature of the alloy or of the solution, the proportions of the metals used in forming the alloy, and the quality of the materials. The moment at which to withdraw the goods, the drying of them, and a hundred little items of care and manipulation, require attention, which experience alone can impart.

Lacquering.—To avoid giving any artificial colour to brass and yet to preserve it from becoming tarnished, it is usual to cover properly cleaned brass with a varnish called "lacquer." To prepare the brass for this, the goods, after being annealed, pickled, scoured, and washed, as already explained, are either dipped for an instant in pure commercial nitrous acid, washed in clean water, and dried in sawdust, or immersed in a mixture of 1 part of nitric acid with 4 of water, till a white curd covers the surface, at which moment the goods are withdrawn, washed in clean water, and dried in sawdust. In the first case, the brass will be bright; in the latter, a dead flat, which is usually relieved by burnishing the prominent parts. Then the goods are dipped for an instant in commercial nitric acid, and well washed in water containing some argol (to preserve the colour till lacquered), and dried in warm sawdust. So prepared, the goods are conveyed to the lacquer room, where they are heated on a hot plate and varnished.

The varnish used is one of spirit, consisting, in its simple form, of 1 oz. of shellac dissolved in 1 pint (imperial) of methylated spirits of wine. To this simple varnish is added such colouring substances as red sanders, dragon's blood, and annatto, for imparting richness of colour. To lower the tone of colour, turmeric, gamboge, saffron, Cape aloes, and sandarach are used. The first group reddens, the second yellows the varnish; while a mixture of the two gives a pleasing orange.

A good pale lacquer consists of 3 parts Cape aloes and 1 of turmeric, to 1 of simple lac-varnish. A full yellow contains 4 of turmeric and 1 of annatto, to 1 of lac-varnish. A gold lacquer, of 4 of dragon's blood and 1 of turmeric, to 1 of lac-varnish. A red, of 32 parts of annatto and 8 of dragon's blood, to 1 of lac-varnish.

Lacquers suffer a chemical change by heat and light, and must be, therefore, kept in a cool place and in dark vessels. The pans in use are either glass or earthenware, and the brushes of camel's hair with no metal fittings. The goods must not be heated beyond boiling point on the hot plate, otherwise they oxidize; and after lacquering, they are again placed on the hot plate, to harden the lacquer.

The different processes having been completed, the goods are fitted together and finished.

Prices.—Rough castings are usually sold at from 1*s.* to 1*s.* 6*d.* per lb.; but if cored, from 2*s.* 6*d.* to 3*s.* per lb. Finished castings are rated at from 2*s.* 6*d.* to 10*s.*, according to the amount of finish put on the goods. Bronzing and lacquering, or dipping and lacquering, are usually charged at about 6*d.* per square foot of surface. Burnishing is generally charged by time.

Wages.—The wages ordinarily paid to brass founders, per week of sixty hours, are, for casters, about 40*s.*; for moulders, 36*s.* to 40*s.*; for fitters, 26*s.* to 32*s.*; for chasers, 36*s.* to 40*s.*; for millers and drawers, 30*s.* to 45*s.*; for pattern makers, modellers, and designers, who are not properly brass founders, 30*s.* to 100*s.* per week; for labourers, about 18*s.* These wages are in advance of those paid twenty years ago by about 25 per cent.

Application to Collateral Arts.—Brass is extensively used in a variety of manufactures. The locksmith constructs many of his locks wholly of brass, and many more partially of that alloy; as, for example, in padlocks, locks for cupboards, tills, desks, boxes, &c. He also employs brass in his players, follows, face plates, stricking plates, handles, roses, and key shields.

The engineer makes use of brass for nearly every journal, for bearings, for plungers, propellers, and general fittings. The plumber employs it for pumps, bath fittings, plugs, cranks, &c.

The optician, electrician, and mathematical instrument maker, for nearly every article which he manufactures. Telescopes, microscopes with their stands, camera lenses and fittings, galvanic batteries and electric machines, ships' compasses, and binnacles, may be named, as indicating the demand on brass.

The stove and fender maker employs brass to relieve and give effect to his polished work; while the musical instrument maker beats it into trumpets and sounding appliances.

The makers of buttons and pins consume no small quantity for their small wares.

The maker of gold leaf beats brass into thin leaf, known as Dutch leaf, which is employed as a substitute for gold in the process of gilding.

The glass-blower employs it in a calcined state to impart colour to his glass. Blue and green colours are produced from unmixed calcined brass; while a red-yellow or chalcedony is obtained when the brass is calcined with sulphur.

The colour maker adds pulverized brass to several of his compositions, and the ship-builder employs it largely for bolts, screws, and sheathing purposes.

The cabinet maker adds great quantities of brass manufactures to his work, which includes in his everyday *routine curtain* poles, bands and hooks, picture *rods, brass locks,* hinges, buttons, rings, handles, roller fittings, sash fasteners and lifters, casters, rollers, hat pins, and nails.

The bell-hanger has nearly all his cranks and pulls made of brass. The gasfitter employs it for his gas lustres, brackets, sun lights, and general fittings and connections. The wire-worker is an important consumer of brass wire for making wire cloth (used by paper makers), as well as for fire guards, cages, &c.

The card-maker is also a considerable employer of brass wire for the woollen manufacturers' cards, and the bookbinder for clasps and corners of his bindings. The traveller's-bag maker, bootmaker, and many other manufacturers in the ramifications of industry employ it in their every-day vocations, and each year adds new applications to this, the most important alloy in the world.

TIN, TIN PLATE, AND TIN ALLOYS.

By Walter Graham.

The word *tin* has been derived from the Saxon *tan*, which is evidently a corruption of *stan*, an abridgment of the Latin word *stannum*.

Tin plate and *tinned plate* are terms employed to indicate iron plates which are covered over with tin. *Tin plate* is used in the same sense in which we speak of silver plate, as when a copper candlestick, teapot, or other article has been coated over with silver, or, in other words, plated, and then called silver plate. The second term, *tinned plate*, is applied to the tinning of an iron, copper, or other plate.

It would appear that man was acquainted with tin almost as early as any other metal. No account of its discovery is on record; but its name occurs in very early writings as a metal in common use. The traditionary forefathers of the Chinese are supposed to have known it, and handed it down to their sons, and it was certainly employed by the Egyptians, being mentioned along with other metals in the books of Moses, and repeatedly in the ancient Hebrew writings, under the name of *Bedil*.

The history of the Phœnicians reveals the fact that for over a thousand years before Christ they obtained tin from the ancient Britons and from the Spaniards. In after-days the Greeks, following the Phœnicians, carried on a considerable trade (as trade was then) in that metal, and termed our islands Cassiterides.

For a long time the Romans endeavoured to discover the market whence the Greeks obtained their tin, and having at length found their way to Britain, the whole commercial world soon became aware of the existence of the tin-producing islands. Indeed, the transactions of the Romans with their semi-barbarous inhabitants are better known to us than those of the Phœnicians or Greeks.

At that time tin was obtained in two ways. First, by washing the soil with water in a manner not unlike that which is carried on at present in some parts of the world for obtaining gold; second, by picking out the ore from the strata by means of tools, such as wood and horn pickaxes, which were gradually exchanged for improved implements made of bronze, the result of which was that deeper mining became more general. At this period, too, we learn something of the mode of conveyance then in vogue. The tin was carted to the coast, and thence in skin canoes to some port, where it was put aboard foreign ships.

There is a term common in Devon and Cornwall to this day, which would indicate that at one time the mining operations of this country were conducted by the Saracens. This term, *Atal Sarasin*, signifies that which has been left by the Saracens, and is applied to such old mines as have been worked out or abandoned.

To the Romans, perhaps, we are indebted for the process of coating the insides of cooking vessels with tin. Both Romans and Greeks at one time silvered the higher class goods of this description, and as tin was then regarded as silver, plus sulphur, it was natural that it should be substituted on account of its price. It has been supposed by some that the *vasa stannea* of the Romans meant such vessels as were simply coated with tin internally, and not solid tin articles, as the words imply.

About the year 1240, a Cornishman, who is said to have been banished from the country, made the discovery of tin in Misina and Bohemia, and the development of these mines was carried on with such energy that it considerably impaired the income of the Earl of Cornwall, brother of Henry III. A charter of privileges was obtained by the earl, laws and taxes were framed for the regulation of mine produce, and a court, known as the Stannary Court, established, to settle all mining disputes. Cornwall thus became the centre of the tin trade, on account of its greater productiveness; though Devon, in former times, had been the principal mining district.

During the sixteenth century the Germans became large purchasers of tin in this country, notwithstanding their own production, and it appears that they employed it in tinning iron plates, for the introduction of which we are indebted to Bohemia. On the other hand, Britain became customers to the Germans for their tin plates. They were very inferior, however, to those which were afterwards manufactured in England, *although they* paved the way to better things. Later on the process of tinning iron plates was brought into Saxony by a Lutheran clergyman, and the trade was successfully carried on in that country.

In the year 1670, an Englishman was sent into Germany to acquire the knowledge of tin plating, whence he returned, bringing with him a number of German workmen, and established the first tin-plating works in this country, in the Forest of Dean. At this period all the smelting operations of this country were conducted with wood or charcoal as fuel, although pit coal was substituted in 1680 by either Pryce or Beecher, both of whom claim the application. The introduction of gunpowder for blasting purposes was another step toward the further development of the tin mines.

In 1720, tin-plate works were erected at Pontypool, in Monmouthshire, and conducted with considerable success; and in the course of events was followed by the opening of the Banca mines, in the Malay Islands; the commencement of the tin-plate works in France; and the discovery of tin in India.

A great improvement was introduced, in 1770, by Jessop and Hancock, in the composition of pewter, which produced increased brightness. The new alloy was called Prince's metal or Britannia metal, the latter a household word, which still holds an important place in commerce. Nothing has ever so much resembled silver or been substituted for that metal.

But the great development of the tin-mining districts is due to the introduction of the steam engine. The ease with which water could be pumped out rendered the situation of a mine of less importance than formerly, and had it not been for the steam engine, the rolling mills, which were then started for the improvement of tin plates, would never have been successful; indeed, from the beginning of this century tin-plate works have gradually spread all over the country, and particularly in places where iron is made.

In Monmouthshire, however, the tin-plate works almost ceased to exist, and their trade was taken up by adventurers, who were little better than gipsies, in Wolverhampton and Bilston. But this was the beginning of the tin-plate trade in these towns—a trade which in the course of seventy years employed upwards of three thousand hands.

The following Table shows the progressive development of our tin mines:

	Ore produced. Tons.	Tin produced. Tons.	Value.
1818	..	4,000	
1825	..	4,358	
1837	..	4,830	
1855	8,776	6,000	
1860	10,400	6,650	
1865	14,122	9,038	
1870	15,234	10,200	
1871	16,898	11,320	£1,556,557
1874	14,039	9,942	£1,077,712

The Banca mines, which according to some are the richest in the world, produce about the same quantity of tin as they did twenty years ago, viz.:

In 1855 .. .. 4233 tons of refined tin.
1860 .. .. 5465 " "
1865 .. .. 4554 " "
1870 .. .. 4672 " "
1874 .. .. 4930 " "

From these and other mines, England purchased in 1832, 700 tons; in 1855, 2487; in 1860, 2911; in 1870, 4715; and in 1875 no less than 16,774 tons, at a value of 1,453,901*l.*

These purchases were rendered necessary on account of the increased demand at home and abroad.

Our home consumption, in round numbers, has been about as follows:

In 1832	3,200 tons
1855	6,000 „
1860	6,300 „
1870	8,700 „
1872	11,500 „

Our exports, which are mainly to France, United States, Russia, Turkey, &c., were:

In 1832	2000 tons
1855	2487 „
1860	2911 „
1870	4715 „
1872	8342 „
1875	5222 „

At the present time there are but few more mines at work than there were twenty years ago. The largest number ever in operation was 174; but many of these were opened by unprincipled speculators, who launched a quantity of bubble companies, in order to fill their own pockets at the expense of the public. Confidence was soon lost in these speculations, and many who were formerly well to do lost their all, for the Stannary Court ordered payment in full of the shares. By the year 1868 the number of mines at work was reduced to 109, though they increased in 1871 to 145.

Tin varies very much in price, and in a single year may rise or fall 30*l.* or 40*l.* The average prices during this century have been, per ton:

In 1810	1820	1830	1840	1850	1860	1870	1872	1874
145*l.*	72*l.*	74*l.*	81*l.*	82*l.*	136*l.*	127*l.*	152*l.*	108*l.*

The amount of tin plates manufactured throughout the country is unknown; but the exports in 1875 amounted to 138,563 tons, the value of which was 3,691,382*l.*, sent chiefly to the United States, Australia, North America, and France.

The average prices of those plates in London, per box of 225 plates $13\frac{3}{4}'' \times 10''$, and weighing 1 cwt., were in

	1832	1857	1860	1865	1870	1872	1874
1c. Charcoal	39/	40/	31/6	29/10	28/10	29/8	37/6
1c. Coke	32/	33/1	25/10	24/5	24/1	25/6	29/11

Properties.—Tin is a metal with a specific gravity of 7·3; lighter than iron, and heavier than zinc. It is isomorphous with the metal titanium, but differs from it in not being brittle. It is malleable, ductile, and tenacious, is capable of being scratched by calc spar, and is a conductor of heat. Under an increase of temperature from 30° to 212° Fahr. it expands $\frac{1}{424}$th part of its length; melts at 424°, and above that heat rapidly oxidizes.

In general appearance it is white, approaching silver, and has a metallic lustre, emits a crackling sound on being bent, has taste and odour on being warmed, with a tendency to crystallize, and combines with other elements of nature in the fixed proportion of 118, hydrogen being 1. Commercial tin is never pure, but always contains arsenic, at least. It is scarcely affected by pure water or air; dissolves readily in hydrochloric acid with evolution of hydrogen gas; is acted on with great energy by nitric acid, and is converted into a white hydrate of the binoxide of tin. Sulphuretted hydrogen in acid or neutral solutions of tin throws down a brown-black precipitate, soluble in liquid potassa. Caustic potash gives a white precipitate, readily soluble in an excess of the precipitant. Ammonia, carbonate of potash, and soda, also yield white precipitates in tin solutions, insoluble in excess.

Tin Ore.—The ore from which tin is obtained is an impure peroxide. Locally, it is called tin-stone, and is of a brown or black colour, though occasionally grey or yellow. It is found in the veins or fissures of the primary rocks, particularly the mica slate, though also in granite and gneiss. These veins or lodes generally run from east to west, and dip north to south, having branches from the main lines ramifying in all directions. The veins are often not more than 3 inches thick; but if the ore is good, that thickness is well worth working. Good ore should yield 70 per cent. of tin; but if it is under 30 per cent. it is regarded as worthless, as it will not pay for smelting.

Tin is also found in alluvial deposits, which are termed sholes or streams. These deposits contain very pure granulated particles, from which is made the best commercial grain tin.

It is also found in the form of a pyrites—a sulphur compound; and although yielding 25 per cent. of tin, is not used for reducing into commercial tin, added to which, it is not very abundant.

The tin-stones from the veins, or the particles from the alluvial deposits, being collected, are well washed in water, and, if required, broken into fragments, and separated into heaps according to their richness. The ore is then subjected to a crushing process in the stamping machine, by which it is reduced to powder, again well washed in water, with considerable agitation of the particles, so as to get rid of as much foreign matter as possible. Some of the ore can be directly passed into the burning house to be roasted—a process which takes twelve to eighteen hours—in a reverberatory furnace, to free it from sulphur and to obtain from it its arsenic. In this process the charges consist of half a ton each, and the arsenic is condensed in collecting chambers connected with the flues.

When the ore ceases to give off further fumes, it is raked out of the furnace into a pit for cooling, and is afterwards washed with water. Should it contain *wolfram*, it is treated with carbonate of soda in a reverberatory furnace, and this results in the formation of tungstate of soda, which is soluble in water. The tin is thus freed from the wolfram by after washing, and the salt of soda obtained for a mordant by evaporation and crystallization.

Reducing.—The ore, whether treated thus or not, is now ready for reduction; the furnaces for this purpose being either reverberatory or cupola. If the former, the charge consists of 1 ton of ore, 1½ cwt. of small coal, and a little lime, all thoroughly mixed. So charged, the furnace is kept under red heat for six or eight hours undisturbed, at which period the experienced operator can tell if the process is complete. If it is not, he will continue the charge, and when finished will run off the slag, the tin itself running into a pan, being skimmed, and then formed into blocks or ingots. In this state, however, it is very impure, and contains much of other metals and foreign ingredients, which have to be removed by the refiner.

Refining.—The blocks or ingots from the smelting process are placed on edge in a reverberatory furnace, and the temperature so arranged that the tin melts and runs off gradually. When run off, a great deal of refuse will be found on the hearth, which is removed and examined, in case it may be worth after-treatment. The metal which is run off is kept in a state of ebullition for some two or three hours, by either burning blocks of wood in it, or by tossing it in the pan which contains it. When the time has elapsed, the metal is allowed to settle, and will be found to consist of three qualities: the top, or the purest; the middle stratum, or the tin which is less pure; and the bottom, which is so impure as to require further refining, and has to be sent back to the furnace. The first two qualities are run into ingots for the market, and this ends the refining process.

Applications of Tin in Manufactures.—First, in the solid form, tin is employed in the manufacture of pipes or tubes for conducting gas, a trade which, it is almost needless to state, has arisen since the introduction of gas for illuminating purposes. These tubes are made either in lengths of 12 to 16 feet, or of 40 or 50 feet. The short-length method is still in use, and consists of drawing a cast pipe, which is 2 feet long and half inch thick, through a series of draw-plates, each a little smaller than its fellow, till the proper size is obtained. The internal gauge is kept right by the mandril on which it is drawn. The bench on which the drawing process is conducted is twice the length of the extended tube, and about a foot broad, with an endless chain running on half its surface and returning below. In the middle of the bench is the stock for the dies or draw-plates. The cast tube is placed on the mandril, and the latter attached by an article not unlike a pair of nippers, which in its turn is fastened to the endless chain driven by hand and steam power. As the tube is drawn through one die after another, it is lubricated by a wash of soap and water till completely formed. The second mode of making tin tubes is based on Hanson's patent of 1837, and consists of pressing warm castings through a mould by hydraulic pressure in such quantity as to make a coil of tubing.

The only other manufacture that I shall mention of the solid form is that of tinfoil, used for silvering mirrors, &c. This is made by hammering thinly rolled plates to about $\frac{1}{1000}$th of an inch thick on an anvil. The process requires care and skill, as the hammerer is very apt to make holes in the sheet.

Secondly, in the plated form, tin is used for coating or plating the surface of other metals. Thus, in making tinfoil, it is now more usual to make leadfoil, and give the surface a wash with tin, and in this form it is sold as tinfoil. It is also the custom of this and other countries to coat the internal surface of copper and iron cooking vessels with tin. This is accomplished by first cleansing the vessels with acid, as well as with sand and water, washing in a solution of sal-ammonia and afterwards with sal-ammonia as a flux, boiling tin within the vessel, and spreading it carefully over the whole surface, pouring off the surplus tin, and well washing the vessel with water to free it from all tracings of the sal-ammonia.

The same principle of tinning is largely adopted in sundry iron goods, as cornice brackets, meat hooks, roller furniture, harness fittings, tacks, and the like. The only difference between the processes is, that these goods are coated all over by placing them in a revolving stoneware vessel over a fire to melt the tin.

By far the largest application of tin in the plated form is that of tinned plates. The iron plates, properly selected, are bent in two like the letter U, and dropped into a bath of dilute muriatic acid, where each plate remains five minutes or so, according to the strength of the acid. The bath commonly consists of 8 lb. of acid [illegible] gallons of water, and this quantity is supposed to clean three thousand six hundred plates. When removed from the bath, they are placed in a red-hot oven till they scale or free themselves from oxidation; after which they are cooled, straightened, and passed [illegible] pair of highly polished rollers under con[illegible] pressure, which imparts their peculiar and [illegible] elasticity. They are next placed for a [illegible] acidified with bran, and then pickled for an hour or two in dilute sulphuric acid, kept in agitation, and warmed by a flue under the pickle tub. The plates are now scoured with sand and water, and all traces of acid removed by washing; then put into a vat of molten grease, where they remain for at least an hour, when they are taken to a vat of liquid tin, and left there for an hour and a half, the tin being kept hot by means of a flue. On being taken out, the plates are allowed to drain on a grating, dipped in very hot tin, and brushed over till it is nearly all removed. Another momentary dip is now given them in very hot and very pure tin—grain tin, by preference—which completely coats the plate with rather more tin than is required, the surplus being removed by immersing the plates in a vat of molten grease, care being taken that the latter is not so hot as to discolour the tin. The plates are now tinned; but they are found to have a thick border along the edge which has been placed downwards in setting. This border is surplus tin, which is removed by dipping the edge into a shallow bath of hot tin, just sufficiently deep to cover it.

Finally, the plates are put into dry bran and well rubbed with hards, till the grease is completely removed, and the plates present a silvery gloss. They are then packed into boxes of hard wood, which are branded with a mark common to the trade, indicating the character and strength, &c., of the contained plates.

The number of plates in each box varies from 100 to 450, and the weight of each box from 98 lb. to 252 lb. The sizes of the plates are from 12¾ × 9½ to 16¾ × 12½ inches, although of late years full-sized iron plates have been tinned, and are now in the market.

Full-sized iron plates (i. e. 6 ft. × 2 ft.) are also tinned for the purpose of afterwards galvanizing; but it is usual to deposit the tin, in this case, by the electrotype process.

Tin-Plate Working.—Most of the manufactured tin wares common to every household are made from the plates just described, although some are tinned afterwards. The art of the tin-plate worker depends more on manual dexterity, than on a large variety of tools and appliances. His tools are few and simple, and may be embraced in a short catalogue, such as steel heads, anvils, swayes, polished hammers, mallets, shears, soldering bolts, bending rollers, compasses, squares, wooden blocks, and benches. Of late years he has had the advantage of the stamping process for raising many articles, which he formerly raised by means of his hammers. If he has a knowledge of practical geometry and geometric drawing, he soon acquires the highest point of skill, for very much time is gained by a rapid setting or drawing out of his work on the surface of his plates, and especially if his work consists of rectangular and figured goods, such as pyramids, cones, and the like. This will appear more striking, if we call to our recollection the variety of goods thus manufactured, viz. lanterns, of a hundred shapes and forms, boxes for travelling, deeds, stores, bonnets, cash and spices, jelly shapes and melon moulds, ice moulds and paste cutters, cake pans and cooking sundries, tea and coffee pots, kettles, pots and pans, pails and flagons, candlesticks, reflectors, funnels, bowls, cans, basins, strainers, graters, dustpans, and toys, not to speak of packing cases, of which an endless quantity is made in every manufacturing town.

Tin goods are often plenished or hammered with polished hammers on polished anvils till they acquire a beautifully smooth and silvery surface. Goods of this nature are called "block-tin goods."

The edges are commonly wired, that is turned over a wire, so as to give strength to the vessel. In uniting sheets or edges together, solder is used, fluxed with resin or muriate of zinc. The stampers employ a large number of tin plates for coffin furniture.

Tin Alloys.—The most common series of tin alloys is that in which tin is united to copper: details of which will be found in the article on Brass Founding.

The next important series is that in which lead is made to unite with tin, "for the safety plugs of steam boilers, in order that the fusion of the plug, and the consequent escape of the water, may occur when the steam exceeds any predetermined pressure, dependent on thermometric temperature." The following are selected from one hundred and two different alloys enumerated by H. Gaulthier De Claubry for the purpose:

1	part of tin to	4	of lead	melts at	500°	Fahr.
1	„	3	„	„	482°	„
1	„	2	„	„	441°	„
1	„	1	„	„	370°	„
1½	„	1	„	„	344°	„
2	„	1	„	„	340°	„
3	„	1	„	„	356°	„

Still lower temperatures are obtainable by adding bismuth to the alloy. It has long been a common trick to make teaspoons of an alloy composed of 3 parts tin, 5 of lead, and 8 of bismuth, which of course melts when placed in hot tea, a fact which surprises the ignorant and gives amusement to the better informed.

Pewter is a tin alloy, of most uncertain composition, and has been stated to be of 20 parts of tin to 1 of copper. Elsewhere it is regarded as an alloy of tin and lead; while a third work orders 2 parts of tin to be fused with one of copper, and the result added to 360 lb. of tin.

The pamphlet published by the Pewterers' Company, in 1772, allows lead to be used in three proportions.

1st, or best, in such proportion, that if the same article is made of tin as is made in pewter, the one will be to the other as 182 is to 183½ in weight.

2nd, or mid quality, is allowed to bear the proportion of 182 to 185½.

3rd, or worst quality, is allowed in the proportion of 182 to 198½.

The French are said to employ 18 per cent. of lead in their pewter wine measures.

Pewter vessels were formerly in every household, but are now much replaced by earthenware and Britannia metal. The goods of this alloy are mostly formed by casting or hammering, and chiefly consist of measures, jugs, salts, peppers, and plates.

Of all the substitutes for silver none has equalled Britannia metal. The seat of its manufacture is Sheffield, and the output at the present time is fully double that of thirty years ago, consisting chiefly of tea and coffee pots, kettles, candlesticks, measures, and spoons. It is composed of 42 parts of tin, 8 of antimony, 4 of copper, and 1 of zinc. The components are melted separately, poured together and properly incorporated in a cast-iron pot. That being done the mixture is run into ingots, which are either used for casting goods, or cast into slabs of 15 inches × 6 inches × 1 inch, for converting into sheet metal.

The cast goods are chiefly knobs, handles, and spoons, the latter being often strengthened by an iron rod or wire in the stalk.

The slabs are passed between highly polished rollers, and kept as much as possible to the width and thickness required. The alloy becomes very hard in the rolling process, and the ends look ragged. The sheets so made are cut into shapes adapted to sundry requirements, and are either stamped between steel or brass dies, or spun in the lathe.

The stamped work is dressed, and as most of the work in Britannia metal is manufactured by uniting several pieces together, the pieces are properly fitted and soldered together to form the articles intended. Teapots and the like are not stamped, but fixed to the chuck of a lathe, and by means of proper tools turned over upon wooden moulds, which process is called spinning, and is not unlike the spinning process of the potter.

The goods after being made are very unseemly, and require the transforming power of another class of workers. They are first washed in boiling water with a good supply of soap, and then buffed with oil and rottenstone on the lathe. The last process is that of hand polishing by female labour, which imparts an astonishing burnished appearance to the goods.

Applications to Collateral Arts.—Tin is the substance from which the manufacturer of putty powder derives his raw material. The more common qualities of putty powder are made by skimming the surface of boiling tin, freed from foreign matter, well washed and ground. The finer sorts are manufactured by dissolving the tin in dilute aqua-regia, and precipitating by dilute ammonia. This precipitate, which is the oxide of tin or putty powder, is well washed and dried, and is otherwise known as butter of tin, and is poisonous.

Mosaic gold is a substitute for gold powder, and is prepared by uniting tin with sulphur in the following manner: 12 parts of tin, 7 of sulphur, and 6 each of mercury and sal-ammoniac, are placed in a glass vessel, and exposed to a low red heat till sublimation is complete, when the bright gold-coloured scales remain at the bottom of the vessel.

Tin is also largely employed for dyers' mordants; and I have already shown how tungstate of soda is produced from the tin ore for this purpose. The sulphates, muriates, and murio-sulphates are employed for fixing reds, crimsons, scarlets, pinks, and yellows; while in combination with bichromate of potash and oxalic acid, the salts of tin are used for fixing blue colours.

In medicine, tin is employed as a cosmetic, and also as an anthelmintic.

ZINC.

By Walter Graham.

Derivation.—The word *zink* is used by the Germans for *zinnig*, which they derive from *zinn*, tin; and *ahnlich*, resembling; and may therefore be translated "a tin-like substance." The commercial blocks or ingots of zinc are known as spelter, from the German *spianter;* while in India, whence it was obtained, it is called *tutenag*. The ores are known as calamine, lapis calammaris, black jack, &c.

History.—At what time the ores of zinc became known to the ancients it is impossible to learn. They were, however, in use among the Chinese, Greeks, and the Romans, who were, however, unaware of their composition, and it was not till 1230 that they began to be noticed by European writers.

In consequence of their abundance, the reduction of them to metals (Von Swab was the first to reduce black jack) became established before the middle of the eighteenth century, and by this time it was understood that the "tutenag" of the Indians, and the "spianter and zink" of the Germans, were one and the same article. The English took to the manufacture, and made use of the discovery of Von Swab.

Up to the beginning of the present century zinc was only manufactured for converting copper into brass, and was regarded as a semi-metallic substance. In 1805, under the patent of Hobson and Sylvester, the metal was produced in the form of sheets through the application of heat, and in an after-patent of Sylvester, the new property was considered so important that it was at once applied to the sheathing of vessels, the lining of houses and roofs, making ridge-plates, eavings, and pipes.

The voltaic action of zinc became the subject of much inquiry, and Sir Humphry Davy refers to it in his "Inquiries into the Best Methods of Protecting the Copper of Ships' Bottoms."

In 1825 it advanced in price from 22*l.* 10*s.* to 41*l.* 10*s.* per ton, through the speculation of Reid and Co., and at the same time the importation of tutenag from India ceased, the English having five or six years previously introduced German spelter into India to compete with that which, they now learned, had come from China.

In 1830, a marked increase appears in the home consumption of zinc. Five years previously it was only 171 tons, while in 1830 it had advanced to 843 tons, and in five years later had reached 2205 tons. Abroad, too, it had come extensively into use, large quantities of corrugated zinc plates, 14 × 12 inches, having been placed on the Jardin des Plantes. From this time the amount gradually increased, being in 1840, 4181 tons; in 1845 (the year in which the duty *was* abolished), 7495 tons; and in 1850, 11,262 tons.

In 1860, the consumption of zinc throughout the world was thus estimated:

Ingot spelter	23,000 tons
Sheets for building purposes	23,000 „
„ utensils	12,000 „
„ ship sheathing	3,500 „
„ packing cases	2,500 „
„ stamped work	1,500 „
„ sundries	1,500 „
	67,000

Although our fathers expected to save the total importation of zinc by manufacturing it in this country, it has become so important in the arts and manufactures that we have been unable to supply our wants, as may be seen from the following Table:

In 1825	5556 tons	In 1845	12,903 tons
1827	5999 „	1850	18,626 „
1830	4422 „	1860	23,481 „
1835	6500 „	1870	28,775 „
1840	4965 „	1872	27,291 „
1842	5500 „	1875	22,719 „

Thus we are importing five times more now than we were fifty years ago.

Our total exports were:

In 1825	6112 tons	In 1845	3,084 tons
1827	6929 „	1850	4,537 „
1830	3479 „	1860	9,482 „
1835	3943 „	1870	10,338 „
1840	4091 „	1872	5,081 „
1842	1900 „	1875	4,896 „

These figures show a very erratic condition, which is perhaps explained by the competition existing between other countries and ourselves in the foreign trade.

The price, per ton, of spelter during the last fifty years may be stated as follows:

	£		£		£		£			£
1825	22½	to	41½	1841	23½	to	40	1860	..	20½
1827	..		15¼	1842	24	to	36	1865	..	22½
1830	..		10¼	1845	15	to	22½	1870	..	18⅞
1835	..		16	1850	..		17	1872	..	23
1840	..		21¾	1855	..		23½	1875	..	23¼

Properties.—Zinc is a bluish-white metal, of considerable lustre and crystalline structure, susceptible of polish. In ingots and castings it is brittle, though tough in sheets, and has a specific gravity, in castings, of 6·8; and in sheets, of 7·2. It is fusible at 773° Fahr., while at temperatures between 200° and 300° Fahr. the brittle substance becomes ductile, and malleable in a marked degree. At 400° Fahr. it is so brittle that it may be reduced to powder, and at red heat it boils and volatilizes, burning in the presence of air with a greenish light. In a state of fusion it unites with copper, tin, nickel, &c., and forms alloys, its combining equivalent being 65.

Zinc is more tenacious than either tin or lead, and is a better conductor of heat under the influence of which it contracts and expands in a less degree than any other metal. At ordinary dry temperatures it tarnishes very slowly; though time, calcareous water, and smoke from wood fires, rapidly destroy it. It is soluble in dilute acids, with evolution of hydrogen gas, and is precipitated by caustic potash, soda, ammonia, sulphide of ammonium, or ferrocyanide of potassium. Impure zinc, or zinc in contact with iron, will present black spots or holes, showing signs of decay.

Ores.—The largest amount is obtained from the ore known as black jack, blende, or sulphuret, which is found in England, Scotland, Saxony, Carinthia, and other European countries. It was long used in Wales for road metal, its real value being unknown. By analysis it produces :

Zinc	68·48
Sulphur	23·16
Iron	8·08
Dross	0·28
	100·00

The ore is found in rocks of all ages, generally associated with lead, though sometimes with tin, iron, copper, and silver. It is either massive or crystalline, cleaves parallel to the faces of the dodecahedron, is generally of a dark brown colour, with a specific gravity of 4·0 to 4·8.

The ore known as calamine is obtained in England, Siberia, and other European countries, and was formerly employed with copper to make brass. By analysis it produces :

Oxide of zinc	64·64
Carbonic acid	35·36
	100·00

It is always associated with silicate of zinc, and is found massive or in crystallized pseudomorphic forms. It has either a brown or yellow colour, cleaves parallel to the faces of the rhombohedron, and has a specific gravity of 4·1 to 4·45.

There are, besides these ores, the red oxide, the silicate, and the sulphate of zinc; but they are less abundant, and do not possess the commercial importance of the preceding ones.

Treatment of the Ores.—The ores having been mined and brought to the surface in the usual way, are first subjected to a process of hand picking, to free them from as much foreign matter as possible, and are then roasted at a moderate red heat in reverberatory furnaces, for the purpose of abstracting the sulphur from the blende, and the carbonic acid from the calamine. The substance which remains after the roasting is an oxide of zinc. It is now necessary to remove the oxygen and obtain the zinc—a rather expensive process at the present day, as it requires 11 tons of coal to obtain 1 of zinc.

The oxide is mixed with coal, and ground under a pair of edge rollers. The mixture is placed in large crucibles, about 4 feet high; each crucible having a central iron tube leading from the cover, through the bottom, to a water cistern placed some 6 or 7 feet under the furnace hearth. The crucibles being filled, are covered, luted, and placed in a dome furnace, with a cone (like that of a glass work), and are surrounded with fuel, and kept at an intense heat for several hours. The carbon from the coal unites with oxygen from the oxide of zinc, and the zinc is set free, passing down through the iron tube, condensing on its way, and dropping into the water of the cistern. Care must be taken to clear the condensing tubes from time to time, as they are liable to get choked. The zinc collected from this operation is melted in iron pots, and run into ingots, forming the "spelter" of commerce. Not more than five charges can be taken from a furnace in fourteen days, and the amount of zinc obtained from the ore, although sometimes as much as 40 per cent., is on the whole not much over 25 per cent.; but, as a rule, the high cost of production, and the low price of the metal, from foreign competition, render the manufacture of zinc in this country unprofitable.

Rolling.—Zinc ingots are made into sheets by simply heating, and rolling between pairs of large rolls, just as in making sheet iron and brass.

Foil and wire have also been produced from this metal; but perhaps its largest application is in the plating of sheets of iron, commonly known as galvanizing.

Galvanizing.—This process was patented by Mr. Craufurd in 1837, and consists of preparing the iron by cleaning in dilute acid and scouring, till all oxide is removed; it is then well washed in clean cold water and dipped in a bath of molten zinc, covered with a thick layer of sal-ammoniac. The dipping is repeated several times, and when sufficient zinc has adhered to the sheet, it is thrown into cold water and afterwards wiped dry.

Wire is galvanized by passing it through the same bath, it being let down at one end and rolled up at the other. Nails are thrown in, left for a minute, shovelled out, and shaken till separated, the zinc soldering them, as it were, together. Heavy work is apt to chill the zinc in the bath, and therefore requires to be heated before immersion.

After the foregoing patent, came that of Mr. Morewood, which consisted in galvanizing plates of iron, which had previously been tinned by electrotype. Mr. Morewood followed up his first patent by others, to improve and extend his process.

By the amalgam process of Mr. Mallett, iron is coated with zinc, by immersion in baths; first, of equal parts of muriate of zinc and sal-ammoniac in solution; and secondly, of 50½ parts of mercury to 323 of zinc ($HgZn^4$) in a molten state, viz. about 680° Fahr. This amalgam has a very strong affinity for iron, and should contain little sodium, not more than 1 lb. to 1 ton of the alloy.

Alloys.—The principal alloy formed by zinc is that known as *brass*, which forms a separate article, and need not therefore be recapitulated here.

Another is that of German silver, otherwise known as electrum, British plate, albata, &c. The commoner qualities vary in proportions, but may be set down as consisting of 7 parts each of zinc and copper, plus 1 of nickel; while the better qualities may be regarded as composed of 2 of zinc, 4 of copper, and 1 of nickel. This alloy has been largely used in the manufacture of spoons, forks, drawing instruments, and harness furniture.

The white copper of China is looked upon as exactly the same as our German silver. A similar alloy is used in the East Indies for making all sorts of utensils, and consists of equal parts of zinc and copper, with a small proportion of lead and tin. The goods made from it are known as Biddery ware, from the name of the town in which it is manufactured.

Applications to Collateral Arts.—I have already spoken of the wide-spread application of zinc to house-building, such as roofing, ridging and guttering, facing walls, furnishing shop fronts, and making sundry ornaments and decorations.

I have moreover stated that zinc and galvanized iron are used in the place of copper and brass for sheathing ships, a practice considerably resorted to in this and other countries.

Zinc is also employed in making a cheap imitation of silver powder, for bronzing purposes, as well as by the engraver, instead of copper; so that we have zinc-plate engraving instead of copper-plate. The work executed on zinc is, however, far from being so sharp or perfect as that on copper.

An interesting use has been made of zinc by the farmer, who makes his cream in zinc vessels, which is said to result in a net increase of 12 per cent. more cream than if made in vessels of any other substance. In 1832 the subject occupied the attention of the Society of Arts, in the 'Transactions' of which will be found much to interest those desiring further information.

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